COMBUSTOR TEST REPORT

CAN BE REPORT

Report S-595

April 4, 1967

NASA Contract: NAS 9-6003



III. INTRODUCTION

The Preliminary Design Columbium Combustor Test is a part of a program to develop a coated, columbium combustion chamber for application with the TMC Apollo S/M RCS engine. In conjunction with the engine testing portion of the program, various other activities are also being undertaken. These activities include metallurgical studies of the combustor material/coating system, combustor structural and thermal analysis and configuration management studies for incorporation of the part into the Apollo S/M RCS engines. Following these efforts, firing tests will be conducted with the final chamber configuration. The results of the preliminary design combustor firing test will be presented in this report.

The Preliminary Design Columbium Combustor Test was conducted to demonstrate the thermal and structural adequacy of the combustor design and the associated seal and attach ring design while operating in the steady state and pulse modes under conditions similar to those required of the qualified Apollo S/M RCS combustor.

Two combustors were utilized in this test. Both combustors were subjected to a nearly identical test program which consisted of a Continuous Run Test, Pulse Operation Survey Test and an Ignition Test (see Figure 1). The details of each test are set forth in the test plan, Reference 1. The data acquired for each test will be presented individually for each combustor in the text of this report. Performance and thermal data acquired from the Apollo S/M RCS Engine Qualification and Supplemental Qualification Tests (see References 3 and 2, respectively) were included in applicable sections of this report for comparison with the data obtained from the Preliminary Design Columbium Combustor Test.

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This Test was Performed under NASA Contract: NAS 9-6003

PRELIMINARY DESIGN COLUMBIUM

COMBUSTOR TEST REPORT

PRELIMINARY DESIGN COLUMBIUM COMBUSTOR TEST REPORT

APRIL 4, 1967

Written by

Approved by

TABLE OF CONTENTS

Section No.	<u>Title</u>	Page
	List of Figures	ii
	References	v
800 80 0	Statement of Quality	vi
I	OBJECTIVE	1
II	SUMMARY	2
III	INTRODUCTION	3
IV	DISCUSSION	5
	A. General	5
•	B. Continuous Run Data	7
	C. Pulse Operation Survey Data	49
	D. Ignition Test Data	58
	E. Post Test Hardware Checks	68
	F. Saturation Techniques	73
v	CONCLUSIONS	74
VI	RECOMMENDATIONS	7 5
Appendix I	Inverted Engine Manifold Detonation	

LIST OF FIGURES

Figure No.	Description	Page
1	Test Matrix	4
2 .	Total Burn Time and Altitude Ignitions Table	6
. 3	Continuous Run Performance Data Tabulation - Combustor No. 2	10
4	Continuous Run Performance Curves - Combustor No. 2	12
5	Continuous Run, Trim Run Data - Combustor No. 2	13
6	Apollo S/M RCS Supplemental Qualification Performance Data Tabulation	14
7	Specific Impulse versus Propellant Temperature (N_2O_4 -MMH)	19
8	Specific Impulse versus Propellant Temperature (N2O4-MMH)	20
9	Mixture Ratio versus Propellant Temperature $(N_2O_4\text{-MMH})$	21
10	Cb-Mo Combustor Performance Comparison Curves (N2O4-MMH)	22
11	Continuous Run Performance Data Tabulation - Combustor No. 1 (400-second run)	23
12	Continuous Run Performance Data Tabulation - Combustor No. 1 (200-second run)	27
13	Continuous Run Performance Curves - Combustor No. 1	29
14	Continuous Run, Trim Run Data - Combustor No. 1	30
15	Continuous Run, Trim Run Data - Combustor No. 1	31
16	Continuous Run Corrected Performance Data Tabulation - Combustor No. 1 (400-second run)	32

LIST OF FIGURES - continued

Figure No.	Description	Page
17	Continuous Run Corrected Performance Data Tabulation - Combustor No. 1 (200-second run)	36
18	Apollo S/M RCS Qualification Test Corrected Performance Data Tabulation	38
19	Cb-Mo Combustor Performance Comparison Curves (N2O4-Aerozine-50)	43
20	Temperature versus Time (Combustor No. 2)	44
21	Temperature versus Time (Combustor No. 1) (400-second run)	45
22	Temperature versus Time (Combustor No. 1) (200-second run)	46
23	Temperature versus Time, Supplemental Qualifi- cation Test	47
24	Temperature versus Time, Qualification Test	48
25	Pulse Operation Survey Prerun Conditions - Combustor No. 2	51
26	Pulse Operation Survey Prerun Conditions - Combustor No. 1	54
27	Ignition Test Data - Combustor No. 2	60
28	Ignition Test Data - Combustor No. 1	63
29	Engine Instrumentation Schematic	67
30	Post Test Photograph (Combustor No. 2)	69
31	Post Test Photograph (Combustor No. 1)	70
32	Pre and Post Test O.D. Measurements - Combustor No. 2	71
33	Pre and Post Test O.D. Measurements - Combustor No. 1	72



LIST OF FIGURES - continued

Figure No.	Description	Page
I-1	Ignition Test Data - Combustor No. 2	1- 8
I- 2	Film Thickness versus Drainage Time (MMH)	I- 9
I- 3	Film Thickness versus Evaporation Rate (MMH)	I-10

REFERENCES

1. MTN 3448, Test Plan, Columbium Alloy Combustion Chamber Development Program - Preliminary Design Chamber Tests; dated 1 September 1966, revised 10 October 1966;

as modified by:

TMC Letter 3024/153-41/5568; Corrections - Marquardt Test Plan MTN 3448; dated 25 January 1967

TMC Letter 3024/153-41/5728; Addendum - Marquardt Test Plan MTN 3448; dated 14 March 1967

- 2. IMC Report A 1068, R-4D Supplemental Qualification Test Report for the Apollo S/M RCS Engine, dated 7 December 1966.
- 3. IMC Report A 1057, Qualification Test Report for Apollo S/M RCS Engine, dated 17 January 1966.

STATEMENT OF QUALITY ASSURANCE

The tests described in this report were conducted under the surveillance of The Marquardt Corporation, Quality Assurance Department. Test procedures followed conformed to those mutually agreed upon by TMC and NASA-Houston.

F. Larango

Chief Inspector, Quality Assurance

The Marquardt Corporation

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Government source inspection was conducted in accordance with the letter of delegation for the Preliminary Design Columbium Combustor Test as authorized by NASA prime contract NAS 9-6003.

J. P. Underwood

DCAS Representative



I. OBJECTIVE

The objective of this report is to present the results of the Preliminary Design Columbium Combustor Test in partial fulfillment of NASA Contract NAS 9-6003.

The purpose of the Preliminary Design Columbium Combustor Test was to demonstrate the acceptability and isolate the problem areas, if any, of a preliminary design C-103 columbium alloy combustor with a slurry applied silicide coating (Sylvania R-512A) and the associated combustor seal and attach ring design for application with the TMC Apollo S/M RCS engine.

II. <u>SUMMARY</u> 2739

Three tests were conducted with each of two combustors: a Continuous Run test, a Pulse Operation Survey test, and an Ignition test. Combustor No. 2 was subjected to the tests in the order stated, and combustor No. 1 underwent testing in reverse order. Both combustors accrued over 1,650 seconds of operation and 10,000 starts (see Figure 2) without exhibiting structural degradation or design deficiencies. Performance and thermal data acquired from the Continuous Run tests were compared to Apollo S/M RCS Qualification and Supplemental Qualification Test results obtained under similar conditions. This comparison showed that engine performance was unaffected by the use of a columbium combustor and that the injector head steady state and soakback temperatures of the columbium engine configuration were lower than that of the qualified Apollo S/M RCS engine injector head assembly. Both combustors underwent over 600 off-design ignitions (in the vertical-up firing position with saturated propellants), programmed to cause chamber overpressures, without incurring a measurable or observed structural degradation.

On the basis of the data generated, the design of the columbium combustor, with its associated attach hardware, is adequate and acceptable without change as the final configuration.

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INTRODUCTION

The Preliminary Design Columbium Combustor Test is a part of a proposition to develop a coated, columbium combustion chamber for application with the TMC Apollo S/M RCS engine. In conjunction with the engine testing portion of the program, various other activities are also being undertaken. These activities include metallurgical studies of the combustor material/coating system, combustor structural and thermal analysis and configuration coangement studies for incorporation of the part into the Apollo S/M RCS engines. Following these efforts, firing tests will be conducted with the final chamber configuration. The results of the preliminary design combustor firing test will be presented in this report.

The Preliminary Design Columbium Combustor Test was conducted to demenstrate the thermal and structural adequacy of the combustor design and the associated seal and attach ring design while operating in the steady state and pulse modes under conditions similar to those required of the qualified Apollo S/M RCS combustor.

Two combustors were utilized in this test. Both combustors were subjected to a nearly identical test program which consisted of a Continuous Run Test, Pulse Operation Survey Test and an Ignition Test (see Figure 1). The details of each test are set forth in the test plan, Reference 1. The data acquired for each test will be presented individually for each combustor in the text of this report. Performance and thermal data acquired from the Apollo S/M RCS Engine Qualification and Supplemental Qualification Tests (see References 3 and 2, respectively) were included in applicable sections of this report for comparison with the data obtained from the Preliminary Design Columbium Combustor Test.

PRELIMINARY DESIGN COLUMBIUM COMBUSTOR

TEST MATRIX

Test	Combustor No. 2 P/N 228949 S/N 0002	Combustor No. 1 P/N 228949 S/N 0003
Ignition	ı	3
Pulse Operation Survey	2	2
Continuous Run	3	1

Notes:

Combustor No. 2 was tested with Engine P/N T-14100, S/N 0001-8 and S/N 0001-9

Combustor No. 1 was tested with Engine P/N T-14100, S/N 0001-10 and S/N 0001-11

The serial number of the engines used for the Ignition Tests were different because the standard Apollo exit bell was replaced by a P/N T-14767 test fixture.

IV DISCUSSION

IV. DISCUSSION

A. General

The Preliminary Design Columbium Combustor Test was conducted in two essentially identical parts. Both parts were conducted per NASA approved test plan MTN 3448 (Reference 1). The first part of the test was conducted between 2 November 1966 and 8 November 1966 with Engine P/N T-14100, S/N 0001-8 and 0001-9, which incorporated preliminary design combustor No. 2 (P/N 228949, S/N 0002). The propellants utilized for this part were monomethylhydrazine and nitric oxide inhibited nitrogen tetroxide (per MSC-PPD-2A). The propellants were fully helium saturated during the ignition testing and partially saturated for the remainder of the tests.

The Preliminary Design Columbium Chamber Test with combustor No. 2 was originally started on 18 October 1966 with Engine P/N T-14200, S/N 0001-12. After the fourteenth run of the Ignition Test, which was the first test scheduled, the test was terminated due to a detonation in the oxidizer manifold which damaged the oxidizer valve standoff and seat. The combustor was not damaged. An investigation of the incident was made. The results of that investigation are presented in Appendix I. The test was reinitiated with Engine P/N T-14100, S/N 0001-8.

The second part of the preliminary design test was conducted between 31 January 1967 and 8 February 1967 with Engine P/N T-14100, S/N 0001-10 and 0001-11 which incorporated preliminary design combustor No. 1 (P/N 228949, S/N 0003). Nitric oxide inhibited nitrogen tetroxide and Aerozine-50 were employed as the propellants for this part of the test. The steady state data acquired from this test are presented both in the "as taken" condition and corrected to standard Apollo conditions. Both propellants were fully helium saturated (see Section F, Method II).

As shown in Figure 1 of this report, both combustors were subjected to a Continuous Run Test, Pulse Operation Survey Test and an Ignition Test. Presented in Figure 2 are the burn time and number of altitude ignitions accrued on each combustor during each of the tests conducted.

TOTAL BURN TIPE AND ALTITUDE INNTTIONS ACCRUED FROM THE PRELIMINARY DESIGN COLUMNIC COLUMNICATION TEST

	ENGINE P/ N S/N 0001-8 COMBUSTOR #	& 0001 - 9	ENCIME P/N TAS/N 0001-10 8 COMBUSTOR # 1	2 0001-11
	Total Altitude Ignitions	Total Eurn Time sec.	Total Altitude Ignitions	Total Burn Time sec.
CONTINUOUS RUN	3	510.0	L	610.0
PULSE OPERATION SURVEY	9763	1137.84	9667	1128.78
DUTTION TEST	706 *	9.20 **	608	7.6
TOTALS	10,472*	1,656.04**	10,279	1746.38

^{*} THIS NUMBER INCLUDES 103 STARTS ON ENGINE P/N T-14200, S/N 0001-12 WITH COMBUSTOR No. 2.

^{**} THIS NUMBER INCLUDES 1.85 SEC OF EURN TIME ACCURED ON ENGINE P/N T-14200, S/N 0001-12 WITH COMBUSTOR No. 2.



B. Continuous Run Test Results

The objectives of the Continuous Run test were to demonstrate engine performance and the thermal and structural adequacy of the columbium combustor and associated attach hardware when subjected to a long steady state run at nominal Apollo conditions.

The Continuous Run test, which was conducted per MTN 3448, Section V-A as amended by Deviation Sheet No. 10, consisted of conducting one 500-second run with combustor No. 2 and two runs, one of 400 seconds duration and the other of 200 seconds, with combustor No. 1.

Both combustors successfully completed the test under the conditions specified, with no indication of design deficiencies. No structural degradation was observed or measured, no engine performance degradation was measured, and the thermal characteristics of the columbium combustor were compatible with the Apollo S/M RCS engine.

Presented in Figure 3 is a tabulation of the steady state performance data obtained from the 500-second run with combustor No. 2 (Engine P/N T-14100, S/N 0001-9). This run was conducted with MMH as the fuel and nitric oxide inhibited N_2O_4 as the oxidizer; both propellants were partially helium saturated per Section F, Method I of this report. The performance data are presented in the "as taken" condition, except for thrust and specific impulse, which were corrected to total vacuum ($P_{cell}=O$). Specific impulse, thrust and mixture ratio (0/F) taken directly from the Figure 3 tabulation are plotted against run time in Figure 4. As shown, the specific impulse was 278.5 seconds at a mixture ratio of 2.10. For this run, the average propellant temperature was 51°F. Figure 5 presents the data from the two trim runs associated with the 500-second run.

The uncorrected performance data acquired from the 500-second rum (run number 4316) of the Apollo S/M RCS Engine Supplemental Qualification Test (Reference 2) conducted under similar conditions, but with standard Apollo hardware, is presented in Figure 6. This performance data was taken at an average mixture ratio of about 2.05 and propellant temperature of 61°F; hence, a direct comparison with the columbium combustor data cannot be made. However, by compiling all applicable data from the Apollo S/M RCS Engine Supplemental Qualification Program and the MMH Design Verification Program, three curves relating the specific impulse to mixture ratio and propellant temperature were made. These three curves: specific impulse as a function of mixture ratio; specific impulse as a function of average propellant temperature; and mixture ratio versus average propellant temperature are presented in Figures 7, 8 and 9, respectively. Using these three relationships, the specific impulse calculated from the columbium combustor

500-second run was corrected to the mixture ratio and propellant temperature of the supplemental qualification 500-second run. A comparative plot of the corrected columbium specific impulse and the supplemental qualification specific impulse versus run time is shown in Figure 10. The performance is identical.

Shown in Figures 11 and 12, respectively, are the steady state performance data taken from the 400-second and 200-second runs with combustor No. 1 (Engine P/N T-14100, S/N 0001-10). These two runs were conducted with fully helium saturated Aerozine-50 and N_2O_4 propellants. The saturation procedure used is set forth in Section F, Method II of this report. A plot of test condition specific impulse, thrust and mixture ratio versus run time for the two runs is depicted in Figure 13. Data tabulated from the 5-second trim runs associated with the 400 and 200-second runs are shown in Figures 14 and 15, respectively.

Figures 16 and 17, respectively, show the 400 and 200-second run performance data corrected to standard Apollo S/M RCS acceptance test conditions. Performance data, corrected to standard acceptance test conditions, acquired from a 500-second run (run number 1356) of the Apollo S/M RCS Qualification Test, which was conducted under conditions similar to the 400 and 200-second runs, is presented in Figure 18. Figure 19 compares the Isp performance of the two engine configurations. The performance was slightly higher with the columbium configuration; however, this difference is attributable primarily to instrumentation accuracy tolerances and normal data scatter.

The thermal characteristics measured during the Continuous Run tests with the two columbium combustors are presented in Figures 20 through 22. For ease in comparing the thermal characteristics of the columbium combustor engines to the standard Apollo S/M RCS engine, Figures 23 and 24 were included.

Plotted in Figure 20 are the injector head, combustor flange and bell nut temperatures as a function of run time for the 500-second run with combustor No. 2. As noted on Figure 20, the maximum injector head and combustor flange soakback temperatures were 250°F and 312°F, respectively. Because of an apparent thermoscope malfunction, a record of the throat temperature was not obtained; however, since other temperatures recorded were similar to previously acquired data this run was not repeated.

Plotted in Figure 23 are the injector head, fuel insert, bell nut and throat temperatures measured during the Orbit Retrograde Test (run number 4316) of the Apollo Supplemental Qualification Test. This test was conducted with MMH fuel as was the test on columbium combustor No. 2. A comparison of Figures 20 and 23 shows that the injector head and bell nut



temperatures from the two engine configurations were essentially identical. Soakback temperatures were not recorded during the Supplemental Qualification Program; however from previous test experience at similar temperatures, the expected head and chamber flange soakback temperatures were probably about 315°F and 350°F, respectively. The combustor throat temperature, as measured during the Supplemental Qualification Test, was about 1950°F.

The head, combustor flange, bell nut and throat temperatures measured from the 400-second and 200-second runs conducted with combustor No. 1 are shown in Figures 21 and 22, respectively. Also shown in Figures 21 and 22 are the maximum head and flange soakback temperatures. In both cases, the maximum head soakback temperature was 260°F and the maximum flange soakback temperature was approximately 315°F. The throat temperatures for these two runs were about 2250°F. Chamber temperature distributions during these tests were also recorded with thermal sensitive, XR, film. These films are being analyzed for inclusion in the Final Thermal Analysis Report.

Plotted in Figure 24 are the various engine temperatures measured during run number 1356 (500-second run) of the Apollo S/M RCS Engine Qualification Test conducted with Aerozine-50 fuel. A comparison of Figures 21, 22 and 24, as expected, shows the columbium engine head and nut temperatures to be similar to the corresponding qualification engine temperatures during the burn test. The columbium engine flange and head soakback temperatures were 315°F and 255°F, respectively. Typical flange and injector head soakback temperatures measured from Apollo S/M RCS production configuration engines are 450°F and 320°F, respectively. The throat temperature of the columbium combustor was about 180°F warmer than that of the Qualification engine. This difference is slightly greater than predicted by the preliminary thermal analysis. The final thermal analysis will be corrected in accordance with these test data.

STEADY STATE TEST DATA

\bigcirc						STEAD	y stati	e test (DAYA				
			Pm PSIA INLET		169.5		168.7		168.6		162.6	a Milan ilingi i yayi mani digama yayi cida ka	
-	11-8-66		P f PSIA SET	ΛP _f .	179.9	74.0	179.9	74.3	179.9	74.5	179.9	74.5	
PAGE	i		P. PSIA	Λρο. psi	170.0	74.5	168.9	74.5	168.2	74.1	169.0	74.9	
No. 2	ATE		Pa. PSIA SET	C*TEST ft-sec	191.1	5039.	191.1	5013.	191•1	5000	191.1	• 2667	
	TEST DATE	I	P TEST - PSIA	C _f	95.5	1.779	4.46	1.780	1.46	1.791	94.1	1.791	
THRUST ENGINE COLUMBIUM CHAMBER 8/N 0001-9		APPENDIX PARAGRAPH.	PCELL - PSIA	spyacTEST	.0780	278.6	.0852	278.7	. 3849	278.3	.0952	270.1	
NGINE CO		APPENDIX !	Fest - Ibs	Fyac TEST - 1bs	7.86	100.5	6.79	6.66	1°16	7.66	7.76	1.66	
HRUST E	-		_ - » Բ	O/F _{TEST}	58.6	2.114	50.9	2.095	51.0	2.093	51.2	2.005	
100 # 1	CELL NO.		w fe cps	^w PTEST •pps	997.	.3508	992.	.3584	.692.	.3581	932.	.3584	
•	CEL		. لسا عود -	^ŵ fTEST -pps	55.4	.1159	51.1	.1159	51.2	.1153	51.4	. 1153	
T-14100		V-A2	,3 o o	°°orest ∙pps	1309.	. 2449	1292.	. 2426	1290.	. 2423	1292.	. 2426	
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ENGINE ASSEMBLY.	TEST NO.	M. T. P.	F D d N	OUTPUT	and the second s		- Comment and Comm	. I	a see a	1			

STEADY STATE TEST DATA

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Q			P . PSIA	AP _f .	179.9	74.5	179.9	74.0				
PAGE_	11-8-66		Pa. PSIA INLET	ΛP _o .	158.7	74.6	169.2	75.1				
8		i	P . PSIA	C*TEST fr-sec	191.1	5007.	191.1	5007.				
COLUMBIUM CHAMBER NO.	TEST DATE	1	P TEST	C _f	94.1	1.791	94.1	1.791				
MBIUM CHAM 0001-9		APPENDIX PARAGRAPH	PCELL PSIA	spyacTEST	.0852	278.7	.0852	278.7				
		APPENDIX	Fest sdi-	FvacTEST - Ibs	7.79	7.66	7.76	7.66				
THRUST ENCINE	-		ր հար - օ Բ	O/F _{TEST}	51.4	2.099	51.8	2.105				
100 # THR	CELL NO.		w f- cps	*PTEST	989.	.3576	988	.3576				
-	CET		Tfmo	^ŵ f⊤EST -pps	١.	.1154	52.0	.1152				
7-14100			· »° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° °	°°TEST -pps	1290.	.2422	1292.	. 2424				
		2	TIME	SG _f	600	.8438	590	. 8 53 6				
SEMBLY	3448	3448 V-A2	NO.	sg°	4515	1.4676	4515	1.4673				
ENGINE ASSEMBLY	TEST NO.	M.T.P.	INPUT	OUTPUT								

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FIGURE 4

STEADY STATE TEST DATA

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-			P m r PSIA		169.1		169.6		The second section of the second section of the second	# 300 State Constitution (1) Constitution (1)	Marine Victoria	
1 OF			P mf PSIA SET	APf.	179.4	73.9	179.8	74.1				
PAGE	11-8-66		Pa. PSIA INLET	APo.	170.0	74.8	169.8	74.3				
α		TRIM RUNS	P a . PSIA SET	C*TEST ft-sec	191.4	5036.	190.9	5049.				
THRUST ENGINE COLUMBIUM CHAMBER NO.	TEST DATE		P TEST	C _f	95.2	1.785	95.5	1.786				
UMBIUM C		PARAGRAPH	PCELL - PSIA	spyacTEST	5	279.5	.0855	280.2		,		
FINE COL		APPENDIX P	Fest - Ibs	F vac TEST 's	9.80	100.5	98.9	100.9		·		
RUST EN	4	A	ار ق ع ع .	O/FTEST F	58.2	2.125	55.0	2.112				
100 # TE	L NO.		w f*	w PTEST (931.	.3597	994.	.3601				
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7-14100			• 30 n	*oTEST	1308.	. 2446	1301.	. 2444	÷			
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EMBLY	3448	3448 V-A2	RUN Oo.	°98	513	1.4633	4514	1.4637		·		
ENGINE ASSEMBLY	TEST NO.	M.T.P.	TUPUI	OUTPUT	A CHARLES AND A CHARLES		:	•				

THE MARQUARDT CORPORATION

SUPPLEMENTAL QUALIFICATION ENGINE # 3 (AMBIENT) ORBIT RETROGRADE TEST STEADY STATE TEST DATA

(FUEL-MMH) (OX-N₂O₄"GREEN)

)							. 011	L-MMH) (OX-1	204 6	KEEN)				
			Pmf PSIA INLET		168.0			167.6		167.8		167.7	Online	
	99-0		Pafe PSIA SET	ΛΡ _f .	179.9		71.2	179.0	71.8	179.0	72.2	179.0	72.0	
μ (P a - PSIA	Λρ _o ·	168.8		72.0	168.1	72.3.	168.5	72.9	168.2	72.5	
	1 4 V	C-4.2	Pa. PSIA SET	C*TEST ft-sec	191.1		5120.	191.1	5081.	191.1	5062.	191.1	5963.	
77	TECT DATE		P CTEST PSIA	C _f	8.96		1.774	95.8	1.781	95.6	1.788	95.7	1,786	
ηεου 	3	PARAGRAPH	PCELL - PSIA	sp _{vac} TEST	•0808		282.3	.0876	281.3	.0884	281.3	•0884	281.0	
Š	 N /S F	PENDIX	r test	F vac TEST	1.66		101.6	6 • 8	100.9	0.66	101.1	ۥ66	101.1	
			السا عود .	O/FTEST	62.7		2.057	56.7	2.043	8 ° 0 9	2.050	61.7	2.055	
	C2		. ¥ f c	*PTEST	1114.		• 3598	1112.	.3588	1114.	.3593	1114.	.3598	
	ū	SEQ # 12	F	wf TEST	60.4		.1177	58.4	.1179	58.5	.1178	6.09	.1178	
ני	700		.³° og og	*°TEST -pps		•	. 2421	1303.	. 2409	1306.	. 2415	1311.	. 2420	
105,986,501	i .	0056	TIME	SGf	5		.8783	30	814	. 09	.8793	06	•878 ₈	
)	3438		RUN NO.	°2°	4316		1.4568	4316	1.4593	4316	1.4592	4316	1.4561	
	ENGINE ASSEMBLI.	a -	INPUT	OUTPUT			•							

SUPPLEMENTAL QUALIFICATION ENGINE # 3 (AMBIENT) ORBIT RETROGRADE TEST STEADY STATE TEST DATA

(FUEL-MMH) (OX-N2O4"GREEN)

					(FUE	L-MINH)	(0x-N ₂ 0 ₄	"GREEN)				
0F5			Pm. PSIA INLET		167.6) man 1	167.6	1	167.6		167.7	
2	99		Paf PSIA SET	ΛΡ _f .	0.671	71.9	179.0	72.0	179.0	71.9	179.0	72.1
PAGE_	10-20-66		Pa. PSIA INLET	ΔPo.	168.3	72.6	168.5	72.9	168.3	72.6	168.2	72.6
	ATE	2 4	Pa. PSIA SET	C*TEST ft-sec	191.1	5065.	191.1	5060.	191.1	5067.	191.1	5063.
0234	TEST DATE	1- 5	P TEST	C _f	7.56	1.786	95.6	1.788	95.7	1.786	92.6	1.788
02		PARAGRAPH	PCELL - PSIA	spyacTEST	•0884	281.1	-0884	281.2	.0884	281.2	.0884	281.4
S/N		APPENDIX F	T test lbs	FvacTEST -	0.66	101.1	0.66	.054 101.1	99.0	101.1	66.0	101.1
	7		ا السائر السائر	O/FTEST	62.1	2.054	62.6	2.054	62.6	2.054	65.9	2.053
	NO.	2	. K. C. P. S. C. P. S	*PTEST	1114.	.3595	1114.	. 3595	1114.	.3594	1114.	•3593
	CELL NO	SEC # 1	ال و الم	[™] fTEST -pps	61.5	.1177	61.8	.1177	62.0	.1177	62.1	.1177
11			,° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° °	°orest -pps	•	. 2418	1311.	. 2418	1311.	.2417	1311.	. 2416
228686-501		9500	TIME	sG _f	120	.8786	150	.8784	180	.8783	210	.8782
i	3438	0	NON NO.	ავ	4316	1.4554	4316	1.4550	4316	1.4548	4316	1.4547
NGINE ASSEMBLY_	EST NO.	- D	INPUT	OUTPUT								

THE MARQUARDT CORPORATION

SUPPLEMENTAL QUALIFICATION ENGINE # 3 (AMBIENT) ORBIT RETROGRADE TEST STEADY STATE TEST DATA (FUEL-MMH) (OX-NOO, "GREEN")

)		. 1			(F	UEL-MMH)	(ox-N ⁵ 0)	4"GREEN")				- Parkers
0F 5	99-0		P mf PSIA INLET		167.7		167.7		167.9		167.8		
3	10-		Pm. PSIA SET	ΛΡ _f .	179.0	71.8	179.0	72.0	179.0	72.2] 0*621	72.2	
PAGE		C-4-2	Pa - PSIA INLET	Λρος. psi	168.5	72.6	168.4	72.7	168.4	72.7	168.4	72.8	
	ATE		Pa. PSIA SET	C*TEST ft-sec	191.1	5077.	191.1	5071.	191.1	5074.	191.1	5069.	
7530	TEST DATE	H	P TEST - PSIA	C _f	95.9	1.782	95.7	1.786	95.7	1.786	95.6	1.788	
- \ - \		PARAGRAPH	PCELL - PSIA	spyacTEST - sec	.0884	281.1	-0884	281.4	.0884	281.6	•0884	281.6	
Z		APPENDIX	f test lbs	FvactEST - lbs	0.66	10111	0.66	101.1	0.66	101.1	0.66	101.1	
	-		ا ا و ا	O/FTEST	63.0	2.051	63.2	2.048	63.4	2.051	63	2.051	
	L NO.	12	. × ec	* ptest	1115.	.3595	1115.	.3591	1114.	•3589	1114.	3588	
	CELL	SEQ # L	۲ چ. ج.,	wfrest .pps	62.3	.1178	62.5	.1178	62.6	.1176	62.9	.1176	
ָר ר			· 3° u	*, °TEST ∙pps	1311.	. 2417	1309.	. 2413	1309.	. 2413	1309.	. 2412	
רחב אפאפפס	3438	9500	TIME	so _f	240	.8781	270	.8780	300	.8779	330	.8779	
) <u>}</u>			NON O	° ວs	4316	1.4544	4316	1.4541	4316	1.4539	4316	1.4536	
) Agadaga ayin	NO. TO	a.	PUT	JTPUT		7		•				pret	

SUPPLEMENTAL QUALIFICATION ENGINE # 3 (AMBIENT) ORBIT RETROGRADE TEST STEADY STATE TEST DATA (FUEL-MMH) (OX-N_O, "GREEN)

)					(F)	UEI-MMH)	(0x-N ₂ 0 ₄	"GREEN)				
0F5			Pmf PSIA INLET		167.7		167.8		167.7	:	167.6	
. 1			Pmf PSIA SET	APf.	179.0	72.1	179.0	72.0	179.0	72.2	179.n	72.1
PAGE	10-20-66	7	Pa. PSIA INLET	Λρο.	168.2	72.6	168.1	72.3	168.2	72.7	168.4	72.9
0234	ATE	C-4-	Pm. PSIA SET	C*TEST ft-sec	191.1	5067.	191.1	5079.	191.1	5064.	191.1	-6905
0	TEST DATE		P TEST - PSIA	C _f	95.6	1.788	95.8	1.784	95.5	1.788	95.5	1.788
\ 		APPENDIX PARAGRAPH	PCELL - PSIA	spyacTEST - sec	-0884	281.5	.0884	281.5	.0880	281.4	0880	281.7
S/S		APPENDIX	Fest · Ibs	F vac TEST - Ibs	0.66	101.1	0.66	101.1	6.8	100.9	6.86	100.9
	, _F -1		T քա _ք բ	O/F _{TEST}	63.6	2.048	63.8	2.048	63.9	2.051	64.0	2.048
,	ON N		. w f	* PTEST	1115.	9590	1115.	.3550	1114.	.3588	1114.	.3584
	CELL	SEQ # 12	۲ شع ۳.۰	wfTEST -pps	62.9	.1178	63.0	.1178	63.1	.2412 .1176	63.3	.1176
100			•° Sd U	°, orest ∙pps	1309.	. 2412	1309.	. 2412	1309.	.2412	1308.	. 2408
228686-501		9500	TIME	SG _f	360	.8778	350	.8777	450	.8777	, 450	.8776
	ı u		NON NO.	ဗိဗ	4316	1.4535	4316	1,4534	4316	1.4533	4316	1.4530
NGINE ASSEMBLY	ON TRE	T P.	ואפטז	OUTPUT								

SUPPLEMENTAL QUALIFICATION ENGINE # 3 (AMBIENT) ORBIT RETROGRADE TEST STEADY STATE TEST DATA (FUEL- MMH) (OX-N2OL"GREEN)

\mathcal{C}	1				(F	UEL- MM	H) (OX-N	20 ₄ "GREEN)				
L. C			PSIA		167.4		67.4					
ហ			PSIA	Apf.	179.0	71.7	170.0 [71.9				
PAGE	10-20-66	N	P . e . P SIA	Λρ _o .	168.1	72.4	168.4	72.9				
	ATE	† - Ω	Pa. PSIA SET	C* TEST ft-sec	191.1-[5077.	191.1	5064.				
1 7	TEST DATE	[P CTEST - PSIA	C _f	7.56	.784	95.5	1.786	·			
0234		APPENDIX PARAGRAPH	PCELL - PSIA	spyacTEST	.9884	281.4 1	.0884	281.0 1		·		
S/N		PPENDIX F	F est	FvacTEST 's	6.86	101.0	98.8					
		4	Tfm _f	O/FTEST F	64.2.	2.051	64.3	2.0567100.8				
	CELL NO.	8	cp «·	*PTEST	1114.	.3587	1112.	• 3588				
	CEL	SEQ # L	T. en.	ŵfTEST ∙pps	63.3	.1176	63.4	.1174			`	
5-501			So o	°o⊤EST •pps	1309.	. 2411	1311.	. 2414				
228686-501		,0056	TIME	SG _f	08 4	.8775	504	•8774				
EMBLY	3438		RUN NO.	°gς	4316	1.4530	4316	1.4529				
ENGINE ASSEMBLY	TEST NO.	M.T.P.	TUPUT	оитрит								

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STEADY STATE TEST DATA

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TESTS OF 4		RUN)	Pmf PSIA INLET		170.4		170.3		170.3		170.3	
		(continuous	P. PsiA SET	AP _f .	176.4	75.3	176.4	75.5	176.4	75.5	176.4	75.5
ESIGN CE	1-31-67	V.A.2 (CON	Pa.	ΛΡο. psi	171.5	76.4	171.5	76.7	171.4	76.6	171.3	76.5
MINARY I		V. V	Pm. PSIA SET	C*TEST ft-sec	183.6	5045.	183.6	5019.	183.6	5018.	183.6	5318.
PROGRAM-PRELIMINARY DESIGN CHAMBER	TEST DATE	Ŧ	P TEST - PSIA	C _f	95.1	1.775	94.8	1.782	94.8	1.781	94.8	1.781
PROGR		APPENDIX PARAGRAPH.	PCELL - PSIA	spyacTEST - sec	.0790	278.3	.0867	278.0	.0371	277.7	.0371	277.1
EVE LOPM S/N		APPENDIX	r test so	FvacTEST - lbs	0.86	8.56	6.76	6.66	97.8	8.66	97.8	8.66
IAMBER D	F-1		T քա _ք - » Բ	O/FTEST	78.9	2.031	79.3	2.027	79.4	2.027	79.5	2.028
STION CI	No. 1		w _f -	*PTEST -pps	1005.	.3588	1008.	.3594	1008.	.3594	1008.	.3564
OY COMBI	COMBUSTOR I		Tfmo.	₩fTEST -pps	76.1	.1134	76.2	.1187	76.1	.1187	75.9	.1137
COLUMBIUM ALLOY COMBUSTION CHAMBER DEVELOPM T-14100	8		. o . s . s . s	°°rEST -pps	1266.	-2404	1261.	.2407	1267.	. 2407	1267.	. 2407
COLUMBI T-14100		ထု	TIME	sG _f	ľ	.8954	30	7508.	99	. 8951	06	1693.
SEMBLY	3448	MTN 3448	RUN NO.	ပိပ္သ	1665	1.4376	1664	1.4375	1667	1.4370	4997	1.4379
ENGINE ASSEMBLY	TEST NO.	M.T.P.	INPUT	OUTPUT	1		T TOTAL THE CONTRACTOR OF THE	neci miero de la composición dela composición de la composición de la composición dela composición dela composición dela composición dela composición de la composición de la composición de la composición dela composición	Person acceptance acceptance	i Dog SANNAN HIN CHESTONIA (FANNAN SIGNA	ORNALIZE STREET, SAVE ST.	*

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TESTS OF 4		S_RUN)	Pm. PSIA INLET		4 170.2	*	4 170.1	m	4 170.0	3	4 170.0	3
HAMBER		(CONTINUOUS RUN)	Pmf PSIA SET	AP _f .	176.	75.	176.	75.	176.	75.	176.	75.
ESIGN CI	1-31-67		Pa. PSIA INLET	$\Lambda_{ m p_o}$.	171.3	76.5	171.3	76.5	171.2	76.5	171.1	76.4
PROGRAM-PRELIMINARY DESIGN CHAMBER OO1-10	DATE 1-3	V.A.2	Pm. PSIA SET	C*TEST ft-sec	183.6	5016.	183.6	5016.	183.6	5006.	133.6	5005.
OGRAM-PRELI 001-10	-		P cTEST - PSIA	C _f	94.8	1.781	94.8	1.778	94.7	1.780	7.46	1.780
PROGR		PARAGRAPH	PCELL - PSIA	spyacTEST	.0871	277.6	.0867	277.3	.0867	277.0	.0867	277.0
SVELOPI S/N		APPENDIX P	F test	vac TEST - Ibs	97.3	8*66	97.7	1.66	97.7	7.66	1.16	7.66
IAMEER DI	F -4	V	T քա _ք թ	O/FTEST	79.5	2.033	79.5	2.034	79.6	2.037	19.6	2.037
STION CE). 1 NO.		. ₩ f° cps	*PTEST (•9001	.3595	1006.	.3595	1006.	.3599	1006.	•3599
ox combu	COMBUSTOR No. 1		Tfm _o	ŵf⊤EST -pps	75.9	.1135	75.8	.1135	75.6	.1185	75.5	.1185
COLUMBIUM ALLOY COMBUSTION CHAMEER DEVELOPI T-14100			.3° 0° 0° 0° 0° 0° 0° 0° 0° 0° 0° 0° 0° 0°	° orest -pps	1269.	.2410	1269.	.2410	1270.	2414	1270.	. 2414
COLUMBI T-14100		œ	TIME	sGf	120	.8951	150	. 8951	180	1568.	210	0563.
	3448	MTN 3448	NON O.	ွင်	1667	1.4379	1667	1.4380	4997	1.4382	4997	1.4334
ENGINE ASSEMBLY	TEST NO.	M.T.P.	TUPUT	OUTPUT		errouger barrouger	· · · · · · · · · · · · · · · · · · ·	erromente acutodo 1000 IP-de	The second		- AN ANTONOON CONTRACTOR	CONTRACT CHARGE SEASON AND THE STATE

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TESTS OF 4.		RUN)	Par-		169.9		170.0		169.9		169.8	
		(continuons	Paf PSIA SET	AP _f .	176.4	75.3	176.4	75.4	176.4	75.4	176.4	75.3
ESIGN CE	1-31-67	i	P PSIA INLET	APo.	170.6	76.0	170.5	75.9	170.5	76.0	170.4	. 6-51
MINARY D		V.A.2.	Pm. PS!A SET	C* TEST ft-sec	183.6	5012.	183.6	5012.	183.6	5006.	183.6	5011.
PROGRAM-PRELIMINARY DESIGN CHAMBER 001-10	TEST DATE		P TEST	C _f	94.6	1.783	94.6	1.781	94.5	1.781	94.5	.783
PROGRAM-		PARAGRAPH	PCELL - PSIA	spyacTEST C	.0867	277.7	.0867	277.4	.0867	277.1	.0867	277.6 1
VELOPA S/N		APPENDIX P	Fest Subs	vac TEST - Ibs	7.76	1.66	91.6	9.66	4.16	5.66	97.6	9.66
CHAMBER DEVELOPA	-	A	ال السائد الده،	O/FTEST	7.67	2.029	7.57	2.029	7.67	2.029	7.61	2.027
	No. 1		w f c	*PTEST (1006.	.3590	1006.	•3590	.9001	.3590	1006.	.3587
ох сомви	COMBUSTOR CELL		T _{fm}	[™] fTEST -pps	75.5	.1185	75.5	.1185	75.5	.1185	75.5	.1185
UM AL	ŏ			woTEST -pps	1250.	. 2405	1200.	. 2405	1200.	.2405	1204.	. 2402
COLUMBI T-14100		89	TIME	sG _f	240	.8950	270	8950	300	. 8950	330	3503.
EMBLY	3/148	MTN 3448	NON O.	ຽວ°	1664	1.4384	1664	1.4384	1664	1.4334	1654	1.4384
ENGINE ASSEMBLY	TEST NO.	M.T.P.	NPUT	OUTPUT	•	•		1		i		



\bigcirc	ı			[l (The Maleyseers.					7-55-20°-7-500-000-000-00-00-00-00-00-00-00-00-00-
TESTS OF 4		RUM)	Paf PSIA INLET		169.7		169.6			169.5			
. 1		(continuous	Pm. PSIA SET	ΛΡ _f .	176.4	75.2	176.4		75.1	176.4	75.0		
PROGRAM-PRELIMINARY DESIGN CHAMBER 001-10 PAGE 4	1-31-67	V.A.2. (CO)	Pa. PSIA INLET	ΛΡος. psi	170.3	75.8	170.1		9•52	170.1	75.6		
MINARY I		V.	Pa. PSIA SET	C*TEST fr-sec	183.6	5006.	183.6		5006.	183.6	5006.		
ogram-frelj 001-10	TEST DATE		P TEST - PSIA	C _f	94.5	1.785	94.5		1.785	94.5	1.785		
PROGR		PARAGRAPH	PCELL - PSIA	spyacTEST	.0867	277.7	.0867	,	277.7	.0867	277.7		
EVELOPA S/N		APPENDIX F	Fest - Ibs	FvacTEST 1	7.76	7.66	7.16		2.66	7.76	7.66		
IAMBER DI		A	_ քա _ք բ	O/FTEST	79.7	2.029	7.67		2.029	79.7	2.030		
STION CE	L NO.		w f G	[₩] PTEST -pps	1006.	.3590	1006.		•3590	1006.	.3590		
ox combu	COMBUSTOR NO.		Tfmo -°F	wfTEST -pps	75.5	.1135	75.4		.1185	75.3			
COLUMBIUM ALLOY COMBUSTION CHAMEER DEVELOPATE $1-1 \mu_{100}$	COMB		Sqn	[™] oTEST -pps	1266.	.2405	1266.		. 2405	1266.	. 2405		
COLUMBI T-14100		φ.	TIME	sG _f	360	. 8950	390		.8950	400	0563.		
EWBLY	3448	MTN 3448	RUN NO.	່ວິດ	4997	1.4384	1665		1.4385	4997	1.4386		
ENGINE ASSEMBLY	TEST NO.	M. T. P.	INPUT	OUTPUT	l						,		

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TESTS	RUN)	P m. PSIA INLET		170.5		170.4		170.4		170.4	
.	(continuous	Paf PSIA SET	AP _f .	176.4	75.4	176.4	75.8	176.4	75.7	176.4	75.7
DESIGN CHAMEER PAGE 1	0 2	Pa PSIA INLET	APo.	171.7	76.6	171.4	76.8	171.4	76.7	171.3	76.6
	V A 2	P . PSIA SET	C* TEST ft-sec	183.7	5035.	183.7	5002.	183.7	5008.	183.7	5012.
PROGRAM-PRELIMINARY 001-10	TEST DATE	CTEST - PSIA	C _f vacTEST	95.1	1.783	9.46	1.798	04.7	1.786	74.7	1.777
7 PROGRAM- 001-10	PARAGRAPH	PCELL PSIA	spyacTEST	•0812	279.0	.0884	279.6	.0888	278.0	.0888	276.7
DEVELOP.	APPENDIX P	Fest - Ibs	vacTEST - lbs	98.3	100.2	98.6	100.6	98.0	100.1	97.5	99.5
CHAMBER DE		T _{fm} t - ° F	O/FTEST	78.7	2.036	80.0	2.039	80.0	2.039	80.0	2.036
No.	02	w fr	PTEST -pps	1004.	.3592	1006.	•3599	1006.	.3599	1006.	.3596
OY COMBUSTOR		ارس جورات	wfTEST	77.6	.1133	77.7	.1184	77.7	.1134	7.77	.1134
UM ALI		·3° c	* oTEST .* - pps	1270.	.2409	1273.	.2415	1273.	.2415	1272.	. 2412
COLUMBI T-14100		TIME	sG _f	5	.8955	30	.8948	09	. 8 948	06	8948
SMBLY	MTN 3448	RUN NO.	° ၁၄°	6664	1.4357	6664	1.4355	6664	1.4356	4999	1.4356
ENGINE ASSEMBLY		INPUT	OUTPUT	• •		ı	1 1	į	. 1		-

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TESTS OF 2		RUN)	Pm. PSIA INLET		170.4		170.4		170.4		170.4		
		(continuous	Pmf PSIA SET	APf.	176.4	75.7	176.4	75.7	176.4	75.7	176.4	75.7	
DESIGN CHAMBER		J	P PSIA INLET	AP _o s	171.3	76.6	171.3	76.6	171.3	76.6	171.2	76.5	
	TE_2-1-67	V.A.2	P. PSIA SET	C*TEST fr-sec	183.7	5011.	183.7	5008.	183.7	5008.	183.7	5007.	
PROGRAM-PRELIMINARY	TEST DATE		CTEST - PSIA	FEST	7.46	1.780	94.7	1.777	7.46	1.778	94.7	1.778	
PROGRAM-		PARAGRAPH	PCELL - PSIA	spyacTEST Cf	• 0838	277.3	• 0888	276.5	.0888	276.8	• 0838	276.8	
DEVELOPI S/N		APPENDIX P	F fest · lbs	vacTEST - lbs	1.16	8*66	97.5	99.5	97.6	9.66	9.16	9.06	
CHAMEER DE	4	A	_ Բ	O/Ftest	80.1	2.037	80.1	2.034	80.1	2.034	80.1	2.034	
	188.1		w f c	*PTEST C	1006.	.3597	1008.	•3599	1008.	•3599	1008.	.3600	
Y COMBUS	COMBUSTOR		Tfmo	wfTEST v	77.4	.1134	77.3	.1186	77.3	.1136	70.9	.1136	`
COLUMBIUM ALLOY COMBUSTION	8		. o o	*OTEST .	1272.	. 2413	1272.	.2413	1272.	.2413	1272.	.2414	
COLUMBI T-1100		3	TIME	sG _f	120	. 8948	150	8 6 4 8	081	• E948	200	3769.	
) 	3448	MIN 3448	RUN NO.	°gς	4999	1.4359	6665	1.4360	4999	1.4361	4999	1.4365	
ENGINE ASSEMBLY	TEST NO.	M.T.P.	INPUT	OUTPUT	l 1		I	I.	1 1		I	-	

PREPARED BY 16W



DATE 2-17-67

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		ERIM)	Pm. PSIA INLET		170.6											
Tests		(TURBINE IRIN)	P m. PSIA SET	AP _f .	176.8		75.0									
N CHAMBER	1-31-67	V.A1(1	Pa. PSIA INLET	APo.	172.2		76.6									
RY DESIG	i I	Λ	P. PSIA SET	C* TEST ft-sec	184.3	1	5049.					-				
RAM-PRELIMINARY DESIGN CHAMBER	TEST DATE	¥.	P TEST - PSIA	C _f vac TEST	95.6		1.779									
RAM-P		APPENDIX PARAGRAPH.	PCELL - PSIA	spyacTEST	.0798		2.612									
PMENT I		APPENDIX	T	FvacTEST - lbs	7.86		100.5				٠.					
CHAMBER DEVELOPMENT I S/N	H		ا لاساد - و التا	O/FTEST	79.3		2.038									
	OR No 1 LL NO.		·> 0	* PTEST - PPS	1006.		.3601								,	
COLUMBIUM ALLOY COMBUSTION	COMBUSTOR CELL		Tfmo	^w fTEST -pps	76.1		.1185									
ALLOY CO			. « « « c	w ^o TEST -pps	1272.		.2416									
LUMBIUM		48	TIME	sGf	5		2558.									,
COLUMBIU ENGINE ASSEMBLY T 14100	3448	MTN 3448	NON O.	ွိ _ပ ွ	4995		1.4376									
ENGINE AS	TEST NO	M.T.P.	INPUT	OUTPUT	.]		Γ .			•						

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TESTS		IM RUN)	Par PSIA INLET		170.3						
		(TURBINE IRIM RUN)	Pm. PSIA SET	AP _f .	176.3	74.8	,				
ESIGN CH	29		Pa. PSIA INLET	Λρο. psi	171.6	76.1					
ALENARY DI	TE8_1_67	V.A.1	P. PSIA	C*TEST fr-sec	183.6	5046.					
PROGRAM-PRELIMINARY DESIGN CHAMBER	TEST DATE		P TEST		95.5	1.769					
: PROGRAM.		APPENDIX PARAGRAPH.	PCELL P	spyactEST Cf	.0816	277.4					
VELOPA.		PENDIX P.	r. 5. 5. 5. 5. 5. 5. 5. 5. 5. 5. 5. 5. 5. 5	FvacTEST SF	98.0	6.66					
AMBER DE	-	AP	۲ ۱۴۳ _۴ ۱۳۶۰	O/FTEST F.	77.7	2.042					
TION CH	No 1 No.		w _f cps	*PTEST O	1004.	.3601					
Y COMBUS	COMBUSTOR NO CELL NO.		۲ - ° ج	wfrest "-	76.5	.1184					`
COLUMBIUM ALLOY COMBUSTION CHAMBER DEVELOPN. T-14100			. o o s o	*OTEST .	1273.	.2417					
COLUMBI T-14100			TIME	sGf	5	0968.					
EMBLY	8448	MTN 3448	No.	°Sc.	4998	1.4370					
ENGINE ASSEMBLY	TEST NO.	M.T.P.	INPUT	OUTPUT	1	r .					

THE MARQUARDT CORPORATION

STEADY STATE TEST DATA CORRECTED TO STANDARD CONDITIONS

\bigcirc						P _{mo} = P _m	STANDAR = 170 PS	D CONDIT	IONS $T_{fm_o} = T_{fm_f}$	75 ⁰ F			
TESTS		US RUN)	ΔP _f		75.3		75.5		75.5		75.5		
SN CHAMBER 1		(continuons	ΔP _o	ر برمود چ	76.4	1.775	76.7	1.783	76.6	1.781	76.5	1.781	
INARY DESIGN	e1-31-67	V.A.2.	C*TEST -ft/sec	P _{chs} - PSIA	5045.	94•8	5019.	94.5	5018.	94.5	5018.	94.5	∆ Ispvacs
PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS OO1-10 PAGE 1 OF	TEST DATE	H	sp _{vacTEST - sec}	C*s-ft/soc	278.3	5052•	273.0	5026.	277.7	5025.	277.7	5024•	MEAN Ispyacs
		DIX PARAGRAPH		F vac _s	2.031	5*66	2.027	9*66	2.027	66.5	2.028	5.99	
MEER DEVE		APPENDIX		.≯ . pps	.3588	.3570	.3594	.3577	•3594	.3579	.3594	•3580	. A Fvacs - Ibs.
USTION CHA	COMBUSTOR No		₩fTEST - pps	. sog.	.1184	.2385	.1187	.2388	.1187	.2390	.1187	.2391	MEAN Fyacs - lbs.
COLUMBIUM ALLOY COMBUSTION CHAMBER DEVELOPN T-14100 S/N	COMEC CELL NO.		P _{chrEST - PSIA}	w.f. s	95.1	.1185	94.8	.1189	8 • 7 /6	.1189	94.8	.1189	∆ O/F _s ME
COLUMBIUM T-14100			DATA STATION SG _f	spyacs - sec	5.8954	278.8	30	278.5	60	273.1	90	273.1	∇
) <u>}</u>	3448	MTN 3448	RUN NO. SG.	0/F _s	4997	2.013	4997	2.008	4997	2.010	4997	2.011	MEAN O/Fs
V ISWEDS	AND MAN ASSET	M.T.P.	TEST DATA	CORRECTED TO STD. COND.		ugan "arah musukakan katan satur 18	· glass er die oberste verfeben						2



	STANDARD	CONDITIONS	
m _o =	Pmf = 170 PSIA	Tfmo = Tfmf	75°F

	C _f ac _s -psi	75.4	75.4	75.4	75.4	75.4	75.4
-ft/sec		Pchs - PSIA 5016 94.					
	C*s -ft/sec 3 277.6	5 - ft/se 3 277 6 502 4 277	5 502 5 502 5 502	5 502 5 502 5 502 7 277	5 502 5 501 5 501	5 502 5 501 5 501	C** -ft/se, -f
- pps	^w p _s F _{vac_s} -pps -lbs -3595 2.033	wps Fvac Pps - lbs 3595 2.0 3582 99 3582 99	% ps 4 3595 3595 3595 3595 3595 3595	% ps 4 3595 3595 3595 3595 3599	3595 3595 3582 3595 3599 3599	3595 3595 3582 3595 3599 3599 3599	3595 3595 3582 3599 3599 3599
		Pps 1185 2394	2394 - 1185 - 2393 - 2393 - 2393	Pps 1185 1185 2393 1185	2394 - 1185 - 1185 - 1185 - 2393 - 2398 - 23	2394 2394 1185 2393 2398 1185	2394 - 2394 - 2393 - 2398 - 2398 - 23998 - 23998 - 23998 - 23998 - 23998 - 23998 - 23998 - 23998 - 23999 - 239
· PSIA		. pps 1 94. 0 . 118	. pps. 1 94. 1 94. 1 94. 8 . 118	. pps 1 94. 1 8 . 118 8 . 118 1 94.	8 -11 94 1 94 1 94 1 94 1 94 1 94 1 94 1	8 -11 94 1 94 1 94 1 94 94 0 94	8 -11 94 1 94 1 94 94 9 94 9 94 9 94 9 94
s SGE	97	.97 .79 .16 2	197 1997 1997 1914	197 197 197 197 197 82	197 197 116 2 197 197 114 2 117 2	116 116 117 117 117 117	197 197 198 197 197 197 197 197 197 197 197
CORRECTED O/F stD. COND.	1.4	• ~ •		\cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot			



STANDARD	CONDITIONS	•		
_ = 170 PSIA	Tém	= T	•	

\bigcirc						P _{mo} =	STANDA P _{mf} = 170 p	RD CONDIT	rions T _{fmo} = T _f	_{mf} 75°F			
ER TESTS		(CONTINUOUS RUN)	ΔP _f		75.3	Clear transition of page states and page state	75.4		75.4		75.3		
DESIGN CHAMES		(CONTIN	ΔP _o	C _f vac _s	76.0	1.783	75.9	1.781	76.0	1.781	75.9	1.783	
MINARY DES	-	VAZ	C* TEST -ft/sec	P _{ch} s.	5012.	94.5	5012.	94.5	5006.	7.76	5011.	94.5	∆ Ispyacs
PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS 001-10	TEST DATE	HA	spyacTEST	C* ft/sec	277.7	5015.	277.4	5013.	277.1	5008.	277.6		MEAN Isp _{vacs} Δ
, ' 「 、		IDIX PARAGRAPH	O/F _{TEST}	Fvac _s	2.029	9*66	2.029	66.5	2.029	4.66	2.027	50	
AMBER DEVE	-	APPENDIX	* PTEST - PPs	.x pgq.	.3590	.3586	.3590	•3588	.3590	.3587	.3587	•	Δ F _{vacs} - Ibs.
BUSTION CH	OR No 1		[₩] fTEST - PPs	.} s ad-	.1185	.2398	.1185	.2400	.1185	•5399	.1185	.2397	MEAN F _{vacs} - Ibs.
COLUMBIUM ALLOY COMBUSTION CHAMBER DEVELOPN T-14100	COMBUSTOR 1		P ^{ch} TEST - PSIA	×. f	94.6	.1168	94.5	.1188	94.5	.1188	94.5	189	Δ O/F _s ME/
COLUMBIU T-14100			DATA STATION SG _f	spyacs	240	277.9	270 .8950	277.4	300	277.2	330 • 8950	277.7	
Ç,	3448	MIN 3448	RUN NO. SG	0/F _s	4997	2.018	4997	2.020	4957	2.619	4997	2.016	MEAN O/Fs
ENGINE ASSEMULT	TEST NO.	M.T.P.	TEST DATA	CORRECTED TO STD. COND.	ar Parker is the country spins to	al Gazzabrocovogovopovogsza, a go	COMP. P. The Print Print Print, 1884, 1884, 1884, 1884, 1884, 1884, 1884, 1884, 1884, 1884, 1884, 1884, 1884,	SISTERA MANAGEMENTA EMPLAYOUTE		- The state of the			



STANDARD CONDITIONS

Pm = Pm = 170 PSIA

Tfm = Tfm 75°F

\bigcirc						Pmo = Pmf	= 170 PSIA	т,	imo = Tfmf	75 ⁰ f	
TESTS		US RUN)	ΔP _f		75.2		75.1		75.0		
GN CHAMBER	+	(CONTINUOUS RUN)	ΔP _o	ر رود چ	75.8	1.785	75.6	1.785	75.6	1.785	
AINARY DESI	1.31	ļ	C* TEST - ft/sec	P _{chs} - PSIA	5006.	94.5	5006.	94.5	5006.	94.5	∆ Ispyacs
PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS	TEST DATE		lspvactest	C* 3 - ff/sec	277.7	5008.	277.7	5007.	277.7	5008.	MEAN Ispoacs AI
-		APPENDIX PARAGRAPH.	0/77231	F vacs	2.029	1.66	2.029	8.66	2.030	8.66	
AMBER DEVEI	-	APPE	w PTEST	ν, ps	.3590	.3590	.3590	•3593	.3590	•3593	Δ Fvacs - lbs.
BUSTION CH	R No 1 No.		wfrest	.≯ os	.1185	.2401	.1185	.2403	.1185	.2403	AN Fracs - lbs.
COLUMBIUM ALLOY COMBUSTION CHAMBER DEVELOPM T-14100	COMBUSTOR No CELL NO		P _{ch} TEST - PSIA	s s sdd -	94.5	.1189	94.5	.1190	94•5	.1190	∆ o/F _s mea
COLUMBIUM T-14100			DATA STATION SG _f	Spyacs	360	277.8	390 .8950	277.7	400	277.8	٥٥
	3448	MTM 3448	RUN NO. SG	0/F _s	4997	2.019	4997	2.020	4997	2.019	MEAN O/Fs
ENGINE ASSEMBLY	TEST NO.	M.T.P.	TEST DATA	CORRECTED TO TO STD. COND.							

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STEADY STATE TEST DATA CORRECTED TO STANDARD CONDITIONS

STANDARD CONDITIONS

Ο.					·	P _m = P	STANDA m _f = 170 P	RD CONDIT	Tons	75 ⁰ F		
R TESTS		S RUM)	ΔP _f isq		75.4		75.8		75.7		75.7	
SIGN CHAMBER		V.A.2. (CONTITNUOUS RUN)	ΔP _o	ر دود	76.6	1.783	76.8	1.798	76.7	1.787	76.6	1.777
MINARY DES.	2-1-	VA2	C* TEST -ft/sec	P _{ch} s	5035.	. 1.46	5002.	94•3	5008	4.4	5012.	94.4
PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS OOT-10	TEST DATE.	NPH .	spyacTEST - sec	C*s -ft/sec	279.0	5040•	279.5	5004•	278.0	5009.	275.7	2 5013. MEAN Ispvacs 2
{		IDIX PARAGRAPH.	0/F _{TEST}	F vacs	2.036.	6.66	2.039	100.3	2.039	99.8	2.036	-65
MEER DEVEL		APPENDIX	*PTEST	.≯ sqq.	.3592	.3575	•3599	.3587	•3599	.3587	•3596	.3585 . A Fvacs - lbs.
COLUMBIUM ALLOY COMBUSTION CHAMBER DEVELOPM T-14100	CELL NO.		*fTEST - PPs	.» sod -	.1183	.2391	.1184	.2401	.1184	.2401	.1184	• 2399 MEAN Fyacs - Ibs.
ALLOY COM	CELL NO.		P chTEST - PSIA	s dd -	95.1	.1184	94.6	.1186	7.46	.1186	7.46	•1186 Δο/F _{\$} ME
COLUMBIUM T-14100			DATA STATION SG _f	spyacs - sec	5 8555	275.3	30	275.7	60 • 8943	278.2	90	276.0
()	3448	MTM 344.8	RUN NO. SG	0/F _s	4999	2.020	4999	2.025	4999	2.025	4999	2.024 MEAN O/Fs
ENGINE ASSEMBLY	TEST NO.	M.T.P.	TEST DATA	CORRECTED TO STD. COND.	Calconnation and account	nichanous service de la companya de la companya de la companya de la companya de la companya de la companya de				Working Riverson, 120		



STANDARD	CONDITIONS
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Court Cour	\$\frac{1}{6}\$	COMBUST	.0							
RUN NG. STATION Poltest "TEST "PTEST OFTEST LEGGEST CTEST APP APPENDIX PARACRAPH V.A.Z. (CONTENTIOUS BLUX) SSO. STATION Poltest "TEST "PTEST OFTEST LEGGEST CTEST APP APPENDIX BLUX SSO. SSO. SSO. SSO. SSO. SSO. SSO. SSO.	RUN NO. S. SG. SO. S. SG. S. SG. S. SG. S. SG. S. S. S. S. S. S. S. S. S. S. S. S. S.		- No.	-		TEST D		67		
80 ₀ SpANA Physics with the state of the s	SG SG SG S SG SG SG SG SG SG SG SG SG SG			APPEI	NDIX PARAGR		1		UOUS RUN)	
0,F ₃	0/F _s 4999	Pchtest - PSIA	Ψ́fEST - pps	* PTEST - PPs	O/FTEST	spyactEST	C* TEST -ff/sec	ΔP _o	ΔP _f	
2.024 277.4 .1186 .2399 .3585 99.4 5012. 94.4 1.781 2.024 277.4 .1186 .2399 .3585 99.4 5012. 94.4 1.781 4999 150 4999 180 4999 180 4999 180 4999 180 4999 2.034 276.8 5008. 76.6 75.7 4999 180 4999 180 4999 180 4999 180 4999 2.034 276.8 5008. 76.6 75.7 4999 180 4999 2.03 4999 4.00 4999 2.03 4	6664	w _f s	.x sqq-	.≯ sqq	F vac _s	C*s - ft/sec	P _{ch}	ر بودع		
2.024 277.4 .1186 .2399 .3585 99.4 5012. 94.4 1.781 4999 150 2.021 276.6 .1187 .2399 .3586 99.2 5010. 94.4 1.777 4999 180 2.021 276.9 .1187 .2400 .3587 99.3 5010. 94.4 1.777 2.022 276.9 .1187 .2400 .3587 99.3 5010. 94.4 1.779 2.022 276.9 .1187 .2401 .3588 99.4 5008. 94.5 1.779	• 4554		.1184	.3597	2.037	277.3		76.6	75.7	
2.021 276.9 .8948 94.7 .1186 .3599 2.034 276.5 5008. 76.6 75.7 2180 2.021 276.6 .1187 .2400 .3587 99.3 5010. 94.4 1.777 2.021 276.9 .1187 .2400 .3587 99.3 5010. 94.4 1.779 2.021 276.9 .1187 .2400 .3587 99.4 276.8 5007. 76.5 75.7 2400 .3587 99.4 5008. 94.4 1.779 2.021 276.9 .1187 .2401 .3588 99.4 5008. 94.5 1.779	•024		.2399	• 3585	7. 66	5012.	4.4	1.781	and the second s	P _{mo} = P _m
2.021 276.6 .1187 .2399 .3586 99.2 5010. 94.4 1.777 E. 4999 180 .4361 .8948 94.7 .1186 .3599 2.034 276.8 5008. 76.6 75.7 2.021 276.9 .1187 .2400 .3587 99.3 5010. 94.4 1.779 4999 200 .4365 .8948 94.7 .1186 .3600 2.034 275.8 5007. 76.5 75.7 2.022 276.9 .1187 .2401 .3588 99.4 5008. 94.5 1.779	.4360	7.46	•1186	•3599	2.034	276.5	5008.	76.6	75.7	STANDA = 170 F
4999 180 -4361 -8948 94.7 -1186 -3599 2.034 276.8 5008. 76.6 75.7 end 2.021 276.9 -1187 -2400 -3587 99.3 5010. 94.4 1.779 -4999 200 -4365 -8948 94.7 -1186 -3600 2.034 275.8 5007. 76.5 75.7 2.022 276.9 -1187 -2401 -3588 99.4 5008. 94.5 1.779	.021	.1187	.2399	.3586	99.2	5010•	94.4	1.777		
2.021 276.9 .1187 .2400 .3587 99.3 5010. 94.4 1.779 4999 200 .4365 .8548 94.7 .1186 .3600 2.034 276.8 5007. 76.5 75.7 2.022 276.9 .1187 .2401 .3588 99.4 5008. 94.5 1.779	4999	94.7	.1186	.3599	2.034	276.8	5008.	76.6	• I	OITIONS T _{fm} = 1
4999 200 4365 .8948 94.7 .1186 .3600 2.034 276.8 5007. 76.5 75.7 2.022 276.9 .1187 .2401 .3588 99.4 5008. 94.5 1.779		1167	.2400	.3587	99.3	5010.	4.46	1.779	-	T _{fmf} 75°
276.9 .1187 .2401 .3588 99.4 5008. 94.5 1	4999	7.46	.1186	.3600	2.034	276.8	5007.	76.5	75.7	F
		-1187	.2401	.3588	7.66	5008.	94.5	1.779		



ENGINE ASSENISLY_	Ehist r	228687			N/S	× 10,7			•		\bigcirc
TEST NO	3324		QUA	QUALIFICATION CELL NO. 1	ENGINE				PAGE(0F	
M.T.P.	0004A	- 1	SEQUENCE # 17		APPE	APPENDIX PARAGRAPH	ו באו ה	-	7-2-62		
TEST DATA	RUN NO. SG	DATA STATION SG	P _{ch} TEST	*frest	* PTEST	0/F _{TEST}	ac TEST	C* TEST	ΔP°	ΔΡξ	
CORRECTED TO STD. COND.	0/Fs	s Pyacs	·.*	sdd • *	sd · ≯	F, 80.	***	-ft/sec	-psi	. sq.	
	1356	. 9056	1.46	· 1175	-pps	-lbs 2.024	276.9	-PSIA 5039.	74.0	75.4	
	2.038	278.0	.1171	.2387	.3558	98.9	5058.	94.6	1.768		P
	1356	30	93.4	.1177	•3559	2.024	274.9	• 7667	74.6	75.8	STAN(no = P _{mf} = 170
	2.034	276.3	-1174	•2389	•3563	98.5	5020.	94.0	1.771		DARD CON Desia
	1356	60	93.2	.1177	.3564	2.028	274.6	4976.	74.8	75.8	
	2.036	275.9	.1176	-2395	.3571	98.5	.6664	93.8	1.776		T _{fm,} 75°F
	1356	9506.	93.3	.1177	.3560	2.025	275.4	4987.	74.5	75.4	
	2.032	276.6	.1178	.2394	.3572	98.8	5008.	94.0	1.777		
	MEAN O/Fs	Δ	ΔO/F _s MEAN	N Fvacs - lbs.	Δ Fvacs -	- Ibs. MEAN	MEAN Ispvocs AI	∆ Ispvacs			

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					P _{mo}	ST AND. = P _{mf} = 170	ARD COND PSIA	ITIONS T _{fmo} = T	fm _e 75	$^{\circ}_{ m F}$		
- or		ΔP _f		75.4		75.2		75.3		75.1		
- 10	L-5.1	∆ P _o	, j	74.6	1.777	74.3	1.772	74.3	1.776	74.5	1.780	
i		C* TEST	P ch	-PSIA 4983	93.9	*0667	94.1	4984.	94.0	4981.	93.9	A Ispyacs
TEST DATE	1 1	1s Pyac TEST	*0 *0 *4/49c	275.2	5005.	274.8	5011.	275.1	5004.	275.5	5005.	MEAN ISPUGES AT
ካ # 2	APPENDIX PARAGRAPH_	O/FTEST	۳. ۵۵۰ -	2.026	98.7	2.028	98.6	2.028	7.86	2.024	98.8	· ibs. MEAN
ION ENGINE	APPEN	* PTEST	·> G	.3559	.3571	.3558	.3573	•3558	.3574	.3553	.3570	∆ Fvacs .
NO. — 1 CHILLON	E # 17	wfrest - pps	· > 0	.1176	.2393	.1175	•2396	.1175	.2397	-1175	.2391	N Fvacs - lbs.
CELL NO	SEQUENCE	P _{chTEST}	* * .	7	.1178	93.3	-1177	93.2	.1177	93.0	.1179	∆ 0/Fs MEAN F
3324	0004A	DATA STATION SG _f	s pyacs	120	276.4	150	276.0	180	276.2	210	276.9	0 Δ
		RUN NO. SG	0/F _s	1356	2.032	1356	2.035	1356	2.036	1356	2.027	MEAN O/Fs
TEST NO.	M.T.P.	TEST DATA	CORRECTED TO STD. COND.		-							



Steady state test data Corrected to standard conditions

)					P _{mo} =	S TANDA = P _{mf} = 170 F	RD COND		_{m,} 75°F	,		
)F565		ΔP _f		74.7		74.9		75.4		75.5		
PAGE3OF 11~3-65	<u> </u>	ΔP _o	C _f s s s	74.0	1.770	74.2	1.776	74.2	1.778	74.1	1.772	
		C* TEST -ft/sec	P _{ch} s.	4998.	94•3	4993.	94•1	4975。	93.8	4985.	93.9	A Ispyacs
DOISTEST DATE	ЬН	spyactEST	C* -ft/sec	275.0	5019.	275.6	5014.	274.9	4991.	274.6	4998.	MEAN Ispone
ħ #	APPENDIX PARAGRAPH	O/F _{TEST}	Fvac _s	2.026	98.7	2.026	98.9	2.024	98.6	2.024	98.4	- Ibs. MEAN
ON ENGINE	APPEN	* PTEST - pps	·} . G .gg .s	.3556	.3575	.3552	.3572	•3553	.3577	•3550	.3573	Δ Fvacs -
QUALIFICATION NO.	臣#17	*frest	° sdd.	.1175	.2396	.1174	.2393	•1175	.2398	-1174	.2397	MEAN Fvocs - lbs.
QUA CELL NO	SEQUENCE # 17	P ^{ch} TEST - PSIA	wf s - pps	93.4	.1180	93.2	•1179	92.9	•1179	93•0	.1176	∆ O/Fs MEA
3324	OOO4A	DATA STATION SG _f	spyacs	240	276.2	270	276.8	300	275.8	330	275.3	Δ
		RUN NO. SG	0/F _s	1356 1.4536	2.031	1356 1.4536	2.030	1356	2.035	1356 1.4536	2.038	MEAN O/F
ENGINE ASSEMBLY TEST NO.	M.T.P.	TEST , DATA	CORRECTED TO STD. COND.									



QUALIFICATION ENGINE

3324

STEADY STATE TEST DATA CORRECTED TO STANDARD CONDITIONS

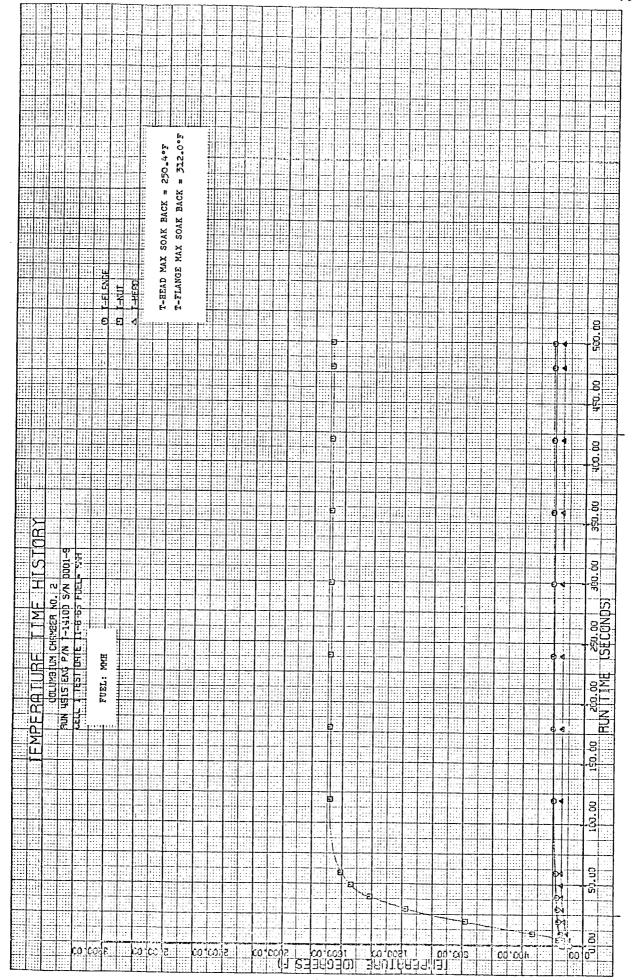
				P _{mo} :	STANDA = P _{mf} = 170 P	RD COND SIA		fm _f 75°F			
	ΔP _f	-	75.5		75.2		75.1		75.1		
T=5 1	A Po	ر روء	74.1	1.776	74.0	1.775	73.8	1.776	73.8	1.776	
	C* TEST -ft/sec	P _{ch} s	4977。	93.8	4977.	93.9	4978.	93.9	4982.	93.9	∆ Ispvacs
РН	spyacTEST	C*s -ff/sec	274.7	*066*	274.5	4993.	274.8	4992.	275.0	4996.	MEAN Ispracs A
APPENDIX PARAGRAPH.	O/F _{TEST}	Fyacs.	2.026	98.5	2.026	98.5	2.022	98.7	2.022	7.86	
APPEN	* PTEST - pps	.≱ o sqq-	.3552	.3577	.3552	.3579	.3551	.3580	.3548	.3577	Δ Fvacs - 1bs.
# 17	∵ frest - pps	* o s	-1174	•2400	-1174	•2400	-1175	•2400	.1174	.2398	N Fvacs - lbs.
SECUENCE	P ch _{TEST} - PSIA	۰ پو چ s sqq -	92.9	1117	92.9	-1178	92.9	•1180	92.9	.1179	ΔO/Fs MEAN
UUU4A	DATA STATION SG _f	spyacs - sec	360 • 9036	275.4	390	275.4	420	275.6	450 • 9036	275.8	0 Δ
	RUN NO. SG	0/F _s	1356 1-4536	2.040	1356 1-4536	2.037	1356 1-4536	2.034	1356 1.4536	2.034	MEAN O/Fs
M.1.r.	TEST DATA	CORRECTED TO STD. COND.									

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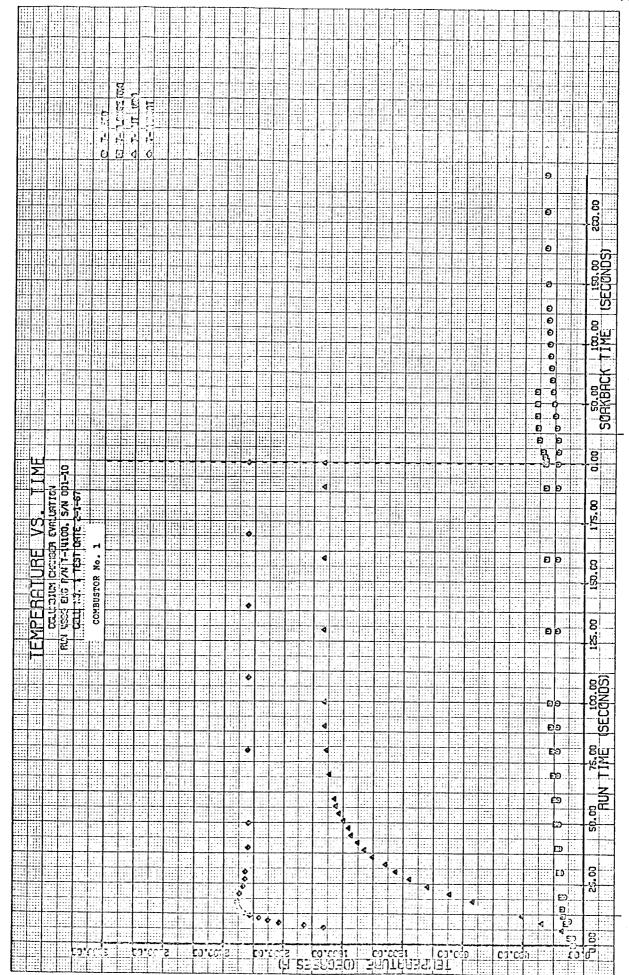
)					f		ANDARD C	ONDITIONS T _{fm}	= T _{fmf} 7	75 ⁰ F		
. OF5			ΔP _f		75.0		74.6			arterioria Communicativa attendente del	en en en en en en en en en en en en en e	
PAGE 5	11/3,	1-5-1	ΔP _o	, s _p ,	73.7	1.774	73.6	1.769				
A4			C*TEST -ft/sec	Pchs.	4985.	94.0	4991.	94.1				∆ Ispvacs
13	TEST DATE	НЫ	spyacTEST - sec	C*s - f1/sec	274.9	*6667	274.4	•6005				MEAN Ispuacs
0013		APPENDIX PARAGRAPH_	O/FTEST	F vacs	2.026	98.6	2.022	98.4				-
S/N	engine # 4	APPEN	* PTEST - pps	.≯ . g sqq	.3546	.3577	.3542	.3575				. A Fvacs - Ibs.
	QUALIFICATION ENGINE	E# 17	₩ fEST - pps	·≯ dd	.1172	•2400	.1172	.2395			·	MEAN Fyacs - lbs.
	QUAI.	SEQUENCE #	P _{ch} TEST - PSIA	× s s -	92.9	.1177	92.9	.1180			• .	Δ O/F _s ME
228687	3324	0004A	DATA STATION SG _f	spyacs.	480	275.7	5C4 • 9036	275.4		,	,	
			RUN NO. SG	0/F _s	1356 1•4536	2.038	1356	2.030				MEAN O/Fs
ENGINE ASSEMBLY	TEST NO.	M.T.P.	TEST DATA	CORRECTED TO STD. COND.	Miles A TON CONTACT HE COURS WHE	e e e e e e e e e e e e e e e e e e e	namen sala masa salaga a salaga gilipa di salaga salaga salaga salaga salaga salaga salaga salaga salaga salag	and the second s	or the analysis of the same of			



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C. Pulse Operation Survey Test Results

The purpose of the Pulse Operation Survey test was to demonstrate the thermal and structural integrity of the combustor when subjected to a large number of pulses with a variety of pulse mode duty cycles.

The test consisted of subjecting both combustors to 80 runs of 120 pulses (minimum) per run with electrical "on" times ranging from 0.010 second to 0.500 second, and electrical "off" times from 0.010 second to 0.300 second.

All runs of this test were successfully completed under the specified conditions without degrading the structural integrity of either combustor.

The Pulse Operation Survey test conducted with combustor No. 2 utilized N_2O_4 , per MSC-PPD-2A, as the oxidizer and MMH as the fuel. Both propellants were partially helium saturated per Section F, Method I. The propellants used for the Pulse Operation Survey test with combustor No. 1 were N_2O_4 , per MSC-PPD-2A and Aerozine-50; both propellants were fully helium saturated per the procedure shown in Section F, Method II of this report.

As specified in the test plan (Reference 1), the following prerun conditions were required:

> Fuel Inlet Temperature, T_{mf} = $40 \pm 5^{\circ}F$ Oxidizer Inlet Temperature, T_{mo} = $40 \pm 5^{\circ}F$ Fuel Inlet Pressure, P_{mf} = 170 ± 2.5 psia (under flowing conditions) Oxidizer Inlet Pressure, P_{mo} = 170 ± 2.5 psia (under flowing conditions) Head Temperature, T_{hd} = $65^{\circ}F$ $^{+55}_{-0}$ °F Cell Pressure, P_{cell} ≤ 0.15 psia

Verification of the required temperatures and pressures for the tests conducted with combustor No. 2 and combustor No. 1 was obtained by data reduction as indicated in Figures 25 and 26 respectively. Since the fuel and oxidizer inlet pressures under steady state flowing conditions are not realized during short pulses, 5-second trim runs were used to establish

the required prerun pressures. These prerun pressures were 168 ± 2.5 psig for the oxidizer inlet and 161 ± 2.5 psig for the fuel inlet. Both are equivalent to a 170 ± 2.5 psia inlet pressure under steady state flowing conditions. All of the parameters were within the specified limits for the record pulse runs. On three trim runs, the head temperature was slightly below the required limit. The cell pressure was less than 0.15 psia prior to each run as verified by inspection stamping the engine logbooks.

COLUMBIUM CHANDER#2 PULSE OPERITION SURVEY
ENGINE P/N T-14100, S/N OOL-9, TEST #3448
TEST DATE: 11-7-56, CELL #1, 27 VOLTS D.C.
VERTICAL DOWN ORIENTATION, PROPELLANTS (FUEL-MAT) (OX.-N₂0₄ "GREEN")

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TEST DATE: 11-7-66, CELL #1, 27 VOLTS D.C. VERTICAL DG#N ORIENTATION, PROFELIANTS (FUEL-MMH) (OX.-)

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COLUMBIUM ALLOY COMBUSTION CHANEER DEVELOPMENT PROGRAM-PRELIMINARY DESIGN CRAMEER TESTS

FULSE OPERATION SURVEY (COMBUSTOR No. 1) EINTHE P/N T-14100, S/N 001-10, TEST # 3448 TEST DATE: 2-2-67, CELL # 1, 27 VOLTS D.C.

VERTICAL DOWN ORIENTATION, PROPELLANTS: (FUEL-A-50) (OX-1204 "GREEN")

* indicates daim points, that are within test plan limits.

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COLUMBIUM ALLOY COMBUSTION CHAMBER DEVELOPMENT PROGRAM-FRELLINDIARY DESIGN CHAMBER TESTS (COMBUSTOR No. 1) OPERATION SURVEY

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COLLIBITION ALLOY COMPUSTION CHANGER DEVELOPMENT PROCRAM-PRELIMINARY DESIGN CHANGER TESTS (COMBUSTOR No. 1) PULSE OPERATION SURVEY

ERCIES P/N T-14100, S/N GOL-10, TEST # 3448
TEST DATE: 2-2-67, CELL # 1, 27 VOLIS D.C.
VERTICAL DOWN CRIENTATION, PROPELIANTS: (FUSI-A-50) (OX-1204 "GREEN")

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D. Ignition Test Results

The purpose of this test was to demonstrate the structural integrity of the combustor and the adequacy of the injector-combustor seal design when the engine is operated at environmental temperatures equal to the minimum safe temperatures of the S/M RCS engines.

Both engines were subjected to 90 runs of from 4 to 9 pulses per run. All valve electrical ON times were 0.012 second, whereas the electrical OFF times varied from 0.100 second to 1.500 seconds. All but the last pulse of each run had a normal 2 ms mechanical fuel lead; the last pulse had either a zero, 6 or 15 ms mechanical oxidizer lead, as prescribed in the test plan (Reference 1). All runs were conducted with the engine in the vertical-up firing position.

As verified by post test inspections, both engines satisfactorily completed all runs at the conditions required without exhibiting any degradation of structural integrity.

Nitrogen tetroxide, per MSC-PPD-2A, and MMH were the propellants used for the ignition testing of combustor No. 2 (Engine P/N T-14100, S/N 0001-8), whereas the ignition test with combustor No. 1 (Engine P/N T-14100, S/N 0001-11) utilized the same oxidizer, but incorporated Aerozine-50 as the fuel. The propellants were fully helium saturated, per Section F, Method II, for the testing of both combustors.

The following prerun limits were specified by the test plan:

Fuel Inlet Pressure, Pmf	=	172 <u>+</u> 2 psia
Oxidizer Inlet Pressure, Pmo	=	172 <u>+</u> 2 psia
Fuel Valve Inlet Temperature, Tmf	. =	40 <u>+</u> 5°F
Oxidizer Valve Inlet Temperature, Tmo	=	40 <u>+</u> 5°F
Head Temperature, Thd	<u>></u>	40°F
Combustor Flange Temperature, Tch1	=	40 <u>+</u> 5°F
Bell Nut Temperature, Tnut	=	0 <u>+</u> 5°F
Cell Pressure, Pcell	≤	0.001 psia

As shown in Figures 27 and 28, the prerun temperatures for the ignition runs with combustors No. 2 and No. 1, respectively, were within the specified range. The head temperature prior to run No. 24 with combustor No. 2 (Engine S/N 0001-8) was 1°F below the specified range, and the test



run was repeated. The cell pressure was less than 0.001 psia, and the oxidizer and fuel inlet pressures were 172 ± 2 psia prior to all runs as verified by inspection stamping the respective engine logbooks.

Two accelerometers, oriented in the manner shown in Figure 29, were mounted on both of the participating engines to obtain an indication of ignition characteristics. As yet, no reliable correlation between acceleration data and chamber overpressure has been made. The data acquired is therefore primarily qualitative and is presented for completeness of documentation. The maximum acceleration recorded during each run with combustor No. 2 (Engine P/N T-14100, S/N 0001-8) is tabulated in Figure 27. Also tabulated in this figure are the ignition delay, pulse number at which peak acceleration occurred and other data associated with the maximum "G" load. Figure 28 presents the maximum accelerations measured during each run with combustor No. 1 (Engine P/N T-14100, S/N 0001-11). Due to electronic saturation of the amplifier used to drive the oscillograph galvanometers, the ignition delay and other time dependent data associated with maximum acceleration were not reducible.

COLUMBIUM CHAMER INNITION OVERPRESSURE TEST
ELLIES P/H I-14100, S/H 0001-8, TEST # 3448
TEST DATE: 11-2-66, CHIL # RRL "G", 27 VOLTS D.C.
VERTICAL UP ORIETTATION, FROPELIANTS: (FUEL-MA) (OK-H20, "GREEN")
COMBUSTOR NO. 2

** DEMOTES RUTS WHERE AX AND AY DIDIN'T RESPOND ON O'GRAPH * INDICATES DATA POINTS THAT ARE WITHIN TEST PLAN LIMITS.

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COLDURAL CHARGER ENTITION OVERPESSING EST ELLE P/A T-14100, S/N COOL-8, TEST # 3448 TEST DATE: 11-2-66, CELL # RRL "G", 27 VOLES D.C. VETTICAL UP ORIENTATION, PROPERLANTS: (FUEL-ME) (CC-F.O. "G

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COLUMNICA CARRER INHITION OVERPRESSURE TEST
ELLIE P/E T-14100, S/H 0001-8, TEST # 3448
TEST EATH: 11-2-66, CRIL # RRL "G", 27 VOLUS D.C.
VERTICAL UP ORIENTATION, PROPEILANTS: (FURL-MA) (CC-12, COMBUSTOR NO. 2

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FIGURE 28

COLLMETUM ALLOY COMZUSTION CHANTER DEVELOPMENT PROGRAM-PRELIMINARY DESIGN CHANTER TESTS IGNITION CHERPRESSURE TEST

EIGIGE P/N T-14100, S/N 001-11, TEST # 3448

TEST DATE: 2-8-67, CELL RRL "G", 27 VOLTS D.C.

VERTICAL UP CRIENTATION, PROFELLAUTS: (FUEL- A-50) (OX- 1204 "CREEN")

(COMBUSTOR NO. LUCTES POINTS TIMT ARE WITHIN 13ST PLAN 4 DENOTES DATA

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TESTS COLLIBIUM ALLOY COMBUSTION CHAMER DEVELOPMENT PROGRAM-PRELIMINARY DESIGN CHAMER IGNITION CHERRESSURE TEST

ENDING P/W T-14100, S/W 001-11, TEST # 3448

TEST DATE: 2-8-67, CELL RRL "G", 27 VOLTS D.C.

1,3 1,1 斯縣 14 13 1,3 i, i 22 12 2,2 VERTICAL UP CRIENTATION, FROFELLARIES: (FUEL- A-50) (OX- 1204 "GREEN") PRE-RUN TEMPERA TURES ~ P (COMBUSTOR No.1) 17 \$\$ \ \$\$\$ 13 12 12 10 10 # # # # # # *** 7,7 3,5 **X**,1 1,3 1,4 1,t | 章 | 章 | 章 | * * * * * * * * 1/2 1/2 章 本 章 章 * DENOTES DATA POLIVIS THAT ARE WITHIN TEST PLAN LIMITS. Pad * * * * * * * * * * * * * * 章 泰 泰 PEAK AY G's 980 21 22 18 18 2377 41 3905 1459 860 2268 81 2258 1249 2268 1219 1189 41 41 1189 1369 1110 PEAK AX DUTY CYCLE MILESTA OF NUCCER 49 50 2 2 3 3 48 45.52 7 52,2 RUST

COLDEBIUM ALLOY COMBUSTION CHANTER DEVELOPMENT PROGRAM-PRELIMINARY DESIGN CHANTER TESTS IGNITION OVERPRESSURE TEST

TEST DATE: 2-8-67, CELL RRL "G", 27 VOLTS D.C. ENGINE P/N T-14100, 8/N 001-11, TEST # 3448

VERTICAL UP CRIENTATION, PROFELIANTS: (FUEL- A-50) (OX- NZO4 "CREEN") * Denotes Dato Points that are within test plan limits.

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	PEAK AX G's		978	401	1316	1187	73	0	292	113	33	153	† 7	779	1177	372	193	362	14	302	968	1038	1038	302	421	391	670	650	411	421	
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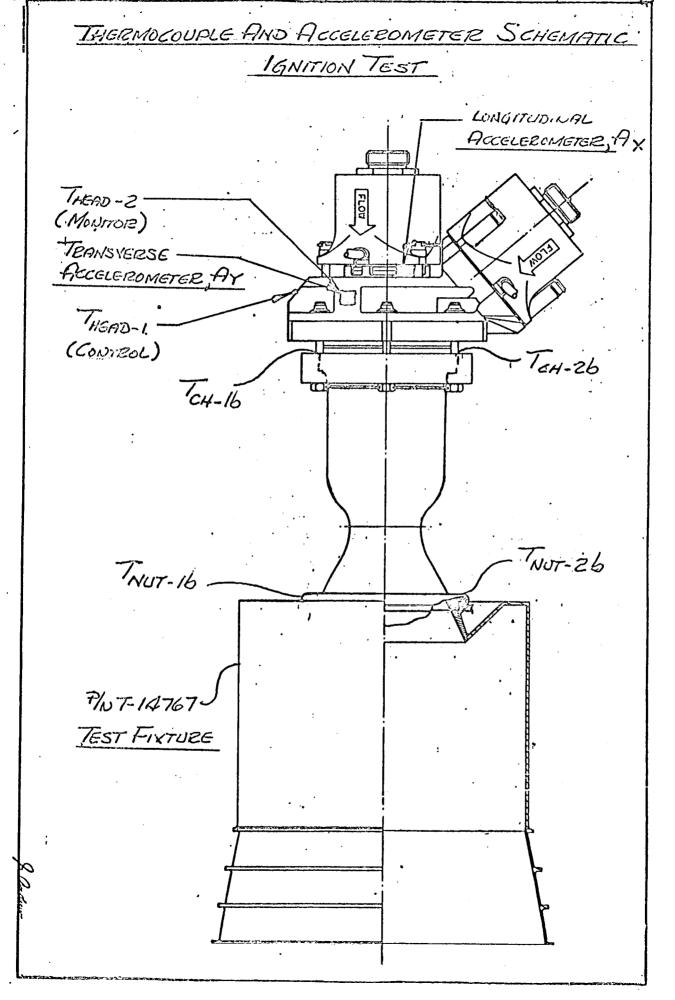
COLUMBTUM ALLOY COMBUSTION CHAMBER DEVSLOPMENT PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS IGNITION CVERPRESSURE TEST

ENGINE P/N T-14100, S/N 001-11, TEST # 3448

TEST DATE: 2-8-67, CELL RRL "G", 27 VOLTS D.C.

VERTICAL UP CRIENTATION, PROPELLANTS: (FUEL- A-50) (OX- 1204 "CREEN") (COMBUSTOR NO. 1) * Denotes data points teat are within test play lidhits,

計 1,2 2,4 1.7 1.1 5. 9 XX 故 23 緯 13 X. FRE-RUN TEMPERATURES ~ % Tch 3,8 2,2 X,x 2,1 1,1 231 Tout ¥ r, 緣 3,2 3,5 * 1,1 ķ 1,2 2,4);; FEAK AY G'8 2078 1369 2088 1659 1669 2058 PEAK AX 352 421 570 541 411 NUMBER OF FULSES IN DUTY CYCLE 0 RUN 8888888



E. Post Test Combustor Checks

The purpose of these checks was to verify that, the structural integrity of the combustor was not degraded as a result, of combustion testing.

A visual inspection, combustor-injector see: leak check and combustor O.D. measurements were made post test.

Combustors No. 1 and No. 2 were not damaged "" deformed as a result of combustion testing.

Visual inspection of the combustors at their respective post test disassemblies reveals no material or coating degree tion.

Post test photographs of combustors No. 2 and No. 1 are presented in Figures 30 and 31, respectively. The post combustion test combustor-injector head seal leakage rate of combustors No. 2 and No. 1 was 2.0 psi per 5 minutes and 2.5 psi per 5 minutes, respectively. These values were verified by TMC inspection stamp in the engine of pook. These leakage rate values represent the total decrease in local propersure (dry, filtered GN2 originally at 175 psi) over a time period of 5 minutes. The Apollo S/M RCS combustor-injector allowable leakage rate is 15 psi per 6 minutes. Presented in Figures 32 and 33 are the pretest and post test outside diameter dimensions of combustors No. 2 and No. 1, respectively. As shown, neither combustor was deformed as a result of testing.

228949 s/N 002 - C103 COMBUSTOR

3

AFTER TEST - SIDE VIEW

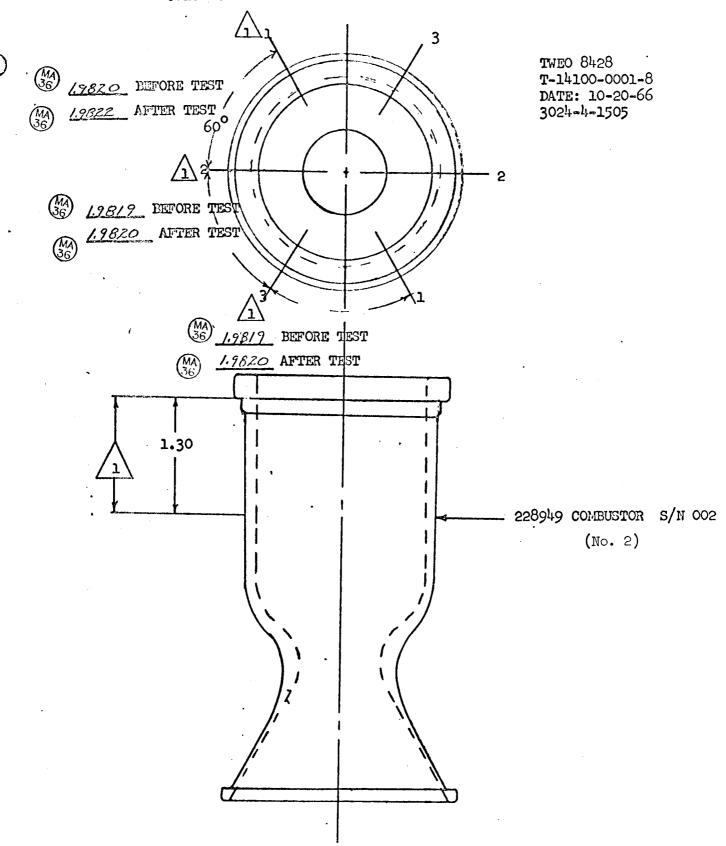
TEST 3448 ATL-PAD G 18 NOV 66

NEG. T3448-4

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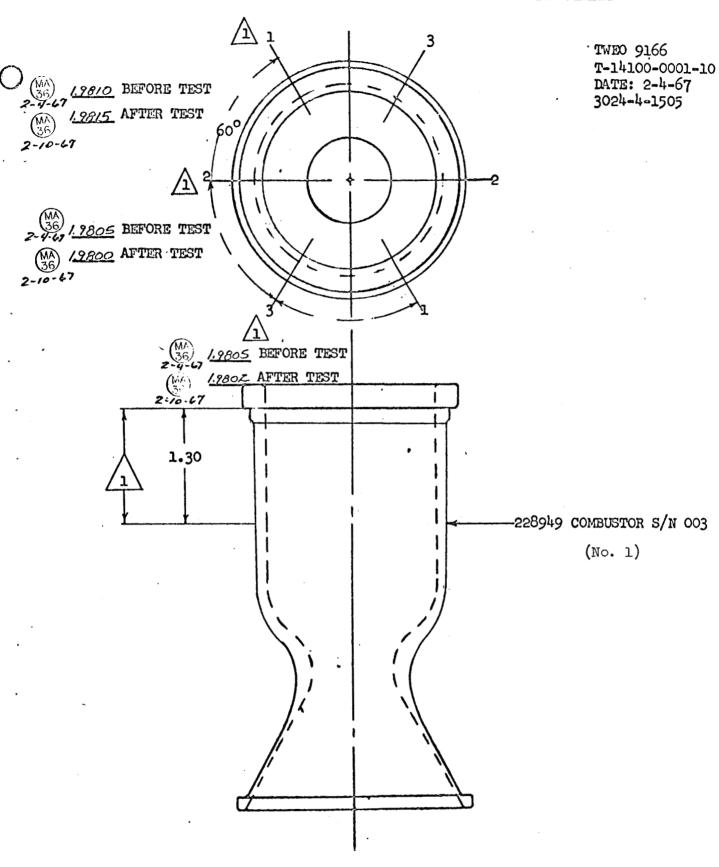
P/N 228949 S/N 003 COLUMBIUM CHAMBER - C103 ALLOY SYLCOR R512A COATING--AFTER TEST

NEG. 8459-10



PLEASE PERFORM AN INSPECTION OF THE COMBUSTOR O.D. AT THE THREE (3) LOCATIONS INDICATED. RECORD THE ACTURAL DIMENSIONS IN THE LOG BOOK THE FOURTH PLACE.

(.XXXX) DIMENSION NO. 2 IS TO BE TAKEN IN LINE WITH THERMOCOUPLE HOLES.





PLEASE PERFORM AN INSPECTION OF THE COMBUSTOR O.D. AT THE THREE (3) LOCATIONS INDICATED. RECORD THE ACTUAL DIMENSTIONS IN THE LOG BOOK THE FOURTH PLACE. (.XXXX) DIMENSION NO. 2 IS TO BE TAKEN IN LINE WITH THERMOCOUPLE HOLES.

F. Propellant Helium Saturation Methods

1. Method I - Partial Saturation

The propellants were partially helium saturated by pressurizing the main storage or pulse tank, whichever was applicable, for a minimum of 24 hours at run pressure (~ 185 psia) and temperature (ambient or 40 + 5°F, as applicable) before the test.

2. Method II - Complete Saturation

The propellants were helium saturated by stirring while at run pressure (172 \pm 3 psia) and temperature (40 \pm 5°F) for a minimum of four hours in the case of the oxidizer, and one hour for the fuel prior to test. This procedure was shown during the Apollo development program to result in essentially complete saturation.

V CONCLUSIONS
VI RECOMMENDATIONS

v. CONCLUSIONS

On the basis of the data acquired from the Preliminary Design Columbium Combustor Test, it was concluded that the thermal characteristics of the columbium combustor and associated attach hardware are compatible with the Apollo S/M RCS engine and Apollo mission requirements, that the mechanical design of the combustor and associated attach hardware is compatible with the Apollo S/M RCS engine, that the structural integrity of the combustor material/coating system is adequate for Apollo S/M RCS engine applications, and that the use of the columbium combustor and associated attach hardware in no way degrades engine performance.

VI. RECOMMENDATIONS

It is recommended that the preliminary design columbium combustor (P/N 228949), combustor-head interface seal (P/N 228948) and attach ring (P/N 228947) be accepted without modification as the final configuration.



APPENDIX I

INVERTED ENGINE INJECTOR HEAD DETONATION ANALYSIS

Introduction

The Preliminary Design Columbium Combustor Test (Ignition Test) commenced on 18 October 1966 with Engine P/N T-14200, S/N 0001-12 which incorporated combustor No. 2. The Ignition Test was stopped after 14 runs because an explosion in the oxidizer manifold damaged the oxidizer standoff and valve seat. The columbium combustor and associated attach hardware were not damaged by the detonation. After assessment of the incident, the preliminary design test was started over with Engine P/N T-14100, S/N 0001-8, which incorporated combustor No. 2. As a result of the investigation, subsequent tests were conducted with a bell nut temperature of zero + 5°F and a head temperature of 40°F or greater.

The explosion occurred on the first pulse of the fourteenth run. The previous run had consisted of nine pulses; 12 ms on and 350 ms off. The time interval between the thirteenth and fourteenth runs was 17 minutes at a cell pressure of about 13 microns (15×10^{-3} mm Hg). The injector head temperature and combustor flange temperature were $14^{\circ}F$ and $19^{\circ}F$, respectively, at the time of the detonation. The propellants utilized were MAH and nitric oxide inhibited N₂O₄. The propellant temperatures were $40 + 5^{\circ}F$. The engine was oriented vertically up. Figure I-1 summarizes the run data. An analytical study was conducted to determine the mechanism that produced the manifold detonation. The results of that analysis are presented herein.

Summary of Proposed Mechanism

The investigation discussed below shows that the following sequence of events, which is strongly dependent upon engine temperature, offers a plausible mechanism for the observed explosion.

During each pulse, fuel is sprayed on the wall from the fuel coolant holes. This amounts to about 3.6×10^{-4} pounds for each 12-millisecond pulse.

During the interval between pulses, a portion of the fuel evaporates. This leaves part of the fuel still on the wall. Almost none of the fuel in the fuel manifold evaporates. Most of the oxidizer leaves the oxidizer manifold during the off time. The chamber pressure created by the evaporating oxidizer suppresses the evaporation of the fuel from the walls.

After the pulse train ends, there is about 3×10^{-3} pounds of fuel on the wall. The fuel manifold contains an additional 1.5×10^{-3} pounds.

The fuel on the wall drains down toward the face of the injector. At the same time, it is vaporizing and flowing out of the exit nozzle. The drainage rate is much faster than the evaporation rate, so that within one second most of the fuel on the wall forms a puddle on the injector face.

The fuel on the injector face flows into the oxidizer manifold injector holes. Capillary action assists in draining the fuel into the holes. The flow rate through the holes is comparable to the drainage rate. Capillary forces are not sufficient to prevent flow through the holes.

The oxidizer manifold substantially fills with fuel before the evaporation from the face eliminates the puddle.

Re-evaporation of the MMH from the oxidizer manifold is a very show and poorly understood process. It is limited by heat flow into the thermal standoff. If the fuel evaporates through the injector holes at the head temperature, it would take about six minutes. The thermal mass of the bottom of the standoff can provide the required heat, but this would cause an 89°F drop in temperature. If the flow rate is limited by heat flow through the liquid, the evaporation time would be over 100 minutes. The emptying may involve two-phase flow through the injector holes. This would increase the emptying rate by some presently unknown amount. Emptying of the fuel manifold occurs more rapidly than emptying of the oxidizer manifold because of the better heat supply there. While the fuel manifold is emptying, evaporation out of the oxidizer manifold will be suppressed.

All the processes described above depend on the temperature of the head and walls of the engine. At higher wall temperatures, the fuel on the walls will evaporate more rapidly between pulses. At higher head temperatures, the vapor pressure of the fuel inside the oxidizer manifold will prevent some of the liquid in the puddle from entering that cavity. At a sufficiently high temperature, the problem should disappear because none of the fuel on the face of the injector can accumulate in the oxidizer manifold.

Analytical Studies

Each of the items noted in the Summary of Proposed Mechanism was the subject of an analytical investigation. Most of the results depend on more basic analyses conducted previously.



A. Fuel Spray on Wall

Approximately 25 percent of the fuel flow occurs through the wall coolant holes in the injector. The nominal fuel flow is approximately 0.12 pound per second. If the manifold is full at the start of the pulse, then

> $w_p = f_{Wt}$ - fuel on wall for one pulse f = 25 percent - fraction sprayed on wall $\dot{w} = 0.12 \text{ lb/sec.}$ - nominal fuel flow rate t = 12 milliseconds - pulse duration for run 13 $w_n = 3.6 \times 10^{-4}$ lb.

This creates a film on the wall approximately 1 \times 10- $\dot{3}$ inch thick over 10 in 2 surface area.

B. Evaporation between Pulses

Significant fuel evaporation does not take place until the exidizer manifold has emptied. While this process is only partially undersuced, it appears that the time to empty the oxidizer manifold at 20°F head temperature is at least 300 milliseconds. Thus, very little fuel will evaporate for 350 milliseconds off time. The fuel evaporation rate at 15°F wall temperature is about 10⁻³ lb/second for 1 mil thickness.

C. Total Wall Fuel

The maximum amount of fuel which could remain on the wall is the amount per pulse multiplied by the number of pulses. Some of this evaporates during a run, and some of it may react with the shutdown oxidizer. Cold flow movies show that very little fuel flows out of the injector during the first pulse. In a string with off times shorter than 350 milliseconds, the fuel manifold will be full when the valve first opens for each of the subsequent pulses.

This fuel forms a film with a thickness of approximately 9×10^{-3} inches.

Appendix _



D. Wall Drainage and Evaporation

The fuel on the walls drains down towards the face of the injec-An analysis of the drainage rate for MMH shows that 70 percent of fuel will reach the face of the injector within one second. The fraction drained versus time is shown in Figure I-2.

Evaporation from the wall occurs simultaneously with the drain-The rate of evaporation for a 20°F wall is shown in Figure I-3.

The time to evaporate 3×10^{-3} lb. will be on the order of 10 seconds or more. Drainage is clearly the phenomenon with the highest rate. hence the fuel on the walls will form a puddle on the injector face.

-E. Flow into the Manifold

The fuel on the dish-shaped face of the injector will cover the injector holes. The liquid will flow into the holes if the fluid wets the interior surface. Since MMH apparently wets most metals, the holes will fill. The fluid will flow through the holes into the manifold if the pressure differential plus gravity force is sufficient to overcome the capillary force holding the liquid in the hole. A puddle of 3×10^{-4} lb. of MMH covering 1 in2 of surface will have a depth of approximately 0.10 inch. The geometry at the end of the hole inside the manifold tends to reduce the capillary forces, hence the estimate given below is conservative.

Flow will occur if

$$\frac{2\sigma}{r} < \rho g(h + t) + P_{ch} - P_{m}$$

Using:

σ = 37 dynes/cm - surface tension coefficient for MMH

r = 0.0017 inch - radius of the oxidizer injector noles

 ρ^2 - 0.902 gm/cm³ - density of MMH

h = 0.2 inch- depth of oxidizer injector holes

 \circ = 0.1 inch - depth of puddle over holes

we find that the capillary forces will be overcome and flow into the manifold will occur if:



The initial pressure in the chamber and manifold will be about 0.0202 psia when the 10 mil thick wall film is evaporating. As the film drains, the chamber pressure will increase, reaching 0.067 psi in approximately 0.3 second when the wall film has thinned down to about 1 mil. During this drainage, a transient pressure gradient will arise between the chamber and the manifold of more than the 0.015 psi necessary to initiate flow.

The flow into the oxidizer manifold will continue until either the driving pressure differential disappears or the manifold fills. At an internal manifold temperature of 8°F, the internal pressure would reach 0.077 psia. This would be sufficient to stop the flow. For lower manifold temperatures, the flow would continue.

The cooling of the oxidizer manifold due to evaporation of the oxidizer after shutdown should provide more than enough cooling to reach this temperature. Temperature drops of this magnitude are observed for engines firing downward, where much less manifold cooling occurs.

The rate of flow from the puddle into the manifold depends on the pressure differential. At 0.049 psi differential plus the gravity head, the flow rate will be:

$$\dot{\mathbf{w}} = \mathbf{C}_{\mathbf{D}} \times \mathbf{A} \times \sqrt{2 \text{ g p } \Delta \mathbf{P}}$$

$$= 0.6 \times 0.00792 \sqrt{2 \times 386 \times 0.0326 \times 0.049}$$

$$= 0.0052 \text{ lb/second}$$

Therefore, the entire manifold could be filled with 1.3×10^{-3} pounds of fuel in 0.25 second. Hence, there will be ample time to fill the manifold.

F. Evaporation from the Face

The MMH in the puddle will not evaporate significantly while the drainage is occurring because of the higher pressures in the chamber created by the fuel on the wall. After the drainage has occurred, there will be about as much fuel remaining on the face as there is in the oxidizer manifold, 1.3 × 10⁻³ pounds of MMH. The evaporation time of this material from a 1 in² puddle can be estimated using the rate for a 10 mil film. (Free convection stirs the liquid below the film surface.) The rate is about 10⁻⁴ lb/second, so that at least 13 seconds will be required to evaporate. This allows ample time to fill the oxidizer manifold with fuel.

G. Re-evaporation from the Oxidizer Manifold

If the oxidizer manifold can fill with MMH as hypothesized above, it would take a very long time to empty it by evaporation alone. The surface area between the preigniter tube and the outer wall is:

$$A_{g} = 0.0427 \text{ in}$$

The total hole area is:

$$A_{\rm H} = 0.00941 \text{ in}$$

and therefore,

$$A_H/A_S = 0.22$$

At 20°F, the evaporation rate would be

$$\dot{\mathbf{w}}_{mo} = 2 \times 10^{-7} \text{ lb/second}$$

The time to empty would be 103 minutes. This time increases to 190 minutes at 10°F.

The liquid column in the manifold may not be stable, however. At 8°F, the vapor pressure is:

$$P_{\mathbf{v}} = 0.077 \text{ psia}$$

The gravity head of a 1-inch column of fluid is only:

$$Y_g = y_{gh}$$

= 0.032 psia

The pressure could force the fluid out of the manifold after the champer pressure drops below 0.045 psia if nucleation of vapor bubbles can occur. At -12°F, the vapor pressure would be 0.032 psia, and the liquid could not be forced out under any conditions.

At some sufficiently high temperature, the liquid would undoubtedly be sprayed out by vaporization at the bottom of the manifold. High speed movies indicate that this may not occur for temperatures less than 20°F for MMH. The mechanics of manifold emptying facing upward is not known well enough to yield a final resolution of this issue.



Conclusions

It seems clear that the explosion under investigation could have been due to the drainage of MMH into the oxidizer manifold after the previous run. The MMH can build up on the wall during a succession of pulses, because the wall temperature and head temperature are too low to permit evaporation of the propellants during the 350 millisecond off time. The accumulated liquid can drain from the walls and cover the oxidizer injector holes with fuel. As the fuel drains, transient pressure differentials are set up which will force the fuel puddled on the face into the oxidizer manifold. This is only possible when the manifold temperature is below about 8°F. The mechanism of emptying the fuel from the oxidizer manifold is not fully understood. If evaporation alone is involved, it could take over 100 minutes. Boiling in the manifold would increase the emptying rate. High speed movies of chamber emptying suggest that boiling will not occur at head temperatures below 20°F.

`All of the steps in this process are temperature dependent. At a sufficiently high temperature, there will be no accumulation. At some other temperature, liquid which accumulates and drains cannot flow into the oxidizer manifold.

The incidence of explosion in inverted engines can be reduced by increasing the temperature of the engine hardware. This conclusion is borne out by an examination of conditions under which explosions have previously occurred. The bulk of such explosions occurred at head temperatures below 40°F.



PRELIMINARY DESIGN COMBUSTOR IGNITION TEST DATA ENGINE P/N T-14200, S/N 0001-12 COMBUSTOR NO. 2

	No. of				peratures ~	°F	Time	Aggalawahilaw
Run	Pulses	On (ms)	Off (ms)	$T_{ m nut}$	$\mathtt{T}_{\mathtt{ch}}$	T _{head}	to Next Run (min)	Acceleration G max.

. 1	1.5	50	62	90	100	100	44	
2	14	12	100	. -1 6	23	28	13	< 500
3	2,	12	100	-16	23	28 .	6	<1100
4	7 .	12	100	- 19	20 <u>+</u> 5	30	6	740
5	7	12	100	- 19	20 <u>+</u> 5	30	8	. 800
6	9	12	100	-17	20 <u>+</u> 5	22	9	1700
7	9	12	100	4-18	20 <u>+</u> 5	25	6	970
8	14	12	350	-18	20 <u>+</u> 5	25	4	1600
9	4	12	350	- 19	20 <u>+</u> 5	23	6	1170
10	7	12	350	- 19	20 <u>+</u> 5	22	5	1400
11	. 7	12	350	-17	20 <u>+</u> 5	21	8	930
12	9	12	350	-17	20 <u>+</u> 5	20	6	570
13	9	12	350	-18	20 <u>+</u> 5	19	17	720
14	4 .	12	600	- 15 {	15) two 14)readings	18.5		9070 1st pulse

DRAINAGE TIME ~ SECONDS

